Next-Generation Polarized ^{3}He Targets for Electron Scattering Experiments

by

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Abstract

Historically, ^{3}He targets for electron scattering experiments have been polarized through spin-exchange optical pumping (SEOP). Polarized laser light passes its circular polarization to alkali metal vapor, which then transfers its polarization to ^{3}He through spin-exchange collisions.

This thesis discusses the basics of SEOP and the polarimetry techniques used in our lab. Narrowband laser and alkali-hybrid SEOP have improved the performance of targets significantly. In alkali-hybrid SEOP, potassium is used together with rubidium for transferring polarization to ^{3}He nuclei. We discussed the data collected over many pure-rubidium targets and alkali-hybrid targets. In the course of analyzing the data, we also studied the "X factor" which limits the highest achievable polarization of ^{3}He.

Because the experiments planned for the 12GeV era in Jefferson National Laboratory (JLAB) will use much higher electron beam current, we are exploring the possibility of using metal (instead of glass) as the entry points (commonly referred to as "end windows") for future targets. We established the metal composition and developed the techniques to incorporate metal to targets without introducing significant spin-relaxation rates. We have successfully demonstrated that future targets can be constructed with metal end windows and are very close to making such targets.

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Contents

List of Tables

List of Figures

Chapter 1

Conclusions

The work presented in this thesis has made it possible to design and begin producing the next-generation polarized ^{3}He targets for use at Jefferson Laboratory. These next-generation targets are being developed and produced in two steps, which are referred to internally at JLab as the Stage-I and Stage-II designs. The Stage-I targets contain a volume of 3 STP liters of ^{3}He, the same quantity that was contained in the cell Antoinette, the results from which were described in Chapter 4. The Stage-II targets, while similar in geometry, are larger and will contain 6 STP liters of ^{3}He. At the time of this writing, the first Stage-I target cell has already been produced and is undergoing bench tests. When using only half the design laser power, the target has already achieved a polarization of 65%, higher than what is needed for actual running (although we note that this is without the depolarizing effects of an electron beam). These early tests are quite encouraging when extrapolated to the full laser power that will be used. Also, the conceptual design of the Stage-II target cells has been completed, and was evaluated in a review, conducted in March of 2016, of the

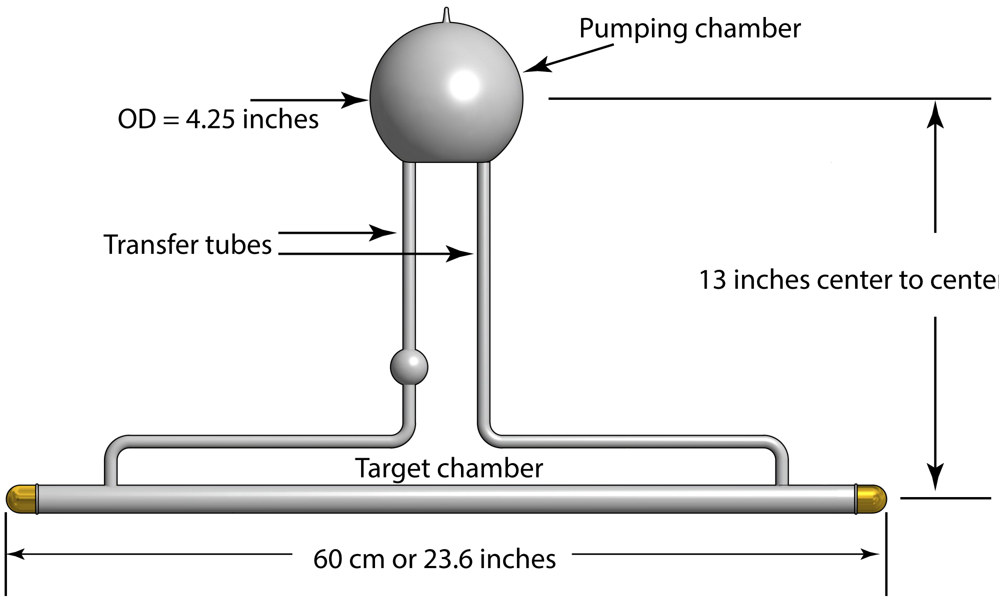

Figure 1.1: Design of next-generation target for upcoming SBS G_E^n experiments.

polarized ^{3}He target that is being built for the Hall A Super Bigbite Spectrometer (SBS) experiment to measure G_E^n, the electric form factor of the neutron. The design for the SBS G_E^n target is shown in Fig 1.1.

1.1 Overall Design of Next-Generation Polarized ^{3}He Targets

The target-cell design illustrated in Fi. 1.1 incorporates multiple features that distinguish it from earlier polarized ^{3}He targets based on spin-exchange optical pumping. The basic geometry is what we refer to as a "convection-style cell, in which the pumping and target chambers are connected by two transfer tubes, one of which is heated, resulting in controllable convective flow between the targets two principle chambers.

The development of convection-style cells was an important part of the thesis work of Peter Dolph, and is well documented in the paper [32]. Subsequent to the work described in [32], our group constructed and tested two convection-style prototype target cells.

Another distinguishing feature of the design shown in Fig. 1.1 is that it is significantly larger than previous target cells, containing 6 STP liters of ^{3}He, and has a target chamber that is 60 cm in length, 50% longer than any target cells previously operated at JLab. The confidence that this target will achieve polarization ¿ 60% in 60 μA of beam came as a direct result of the work described in Chapter 4, and published in Reference [60]. While much of the data presented in ref. [60] were obtained prior to the work described here, most of the analysis was performed as part of this work, including a determination of the coefficient characterizing spin-exchange between potassium and ^{3}He.

Data included in ref. [60] that were specifically obtained as part of this thesis work included all of the studies of the cell Antoinette, which contained roughly 3 STP liters of ^{3}He. While target-cells containing 3 STP liters of ^{3}He were used during the first Hall A G_E^n experiment, commercial narrow-band high-power diode-laser arrays, which are critical to achieving high performance, were not yet available during both testing and the experiment itself. Thus, Antoinette was the first target cell tested with narrow-band lasers that contained both 3 STP liters of ^{3}He and an alkali-hybrid mixture for optical pumping. As such, Antoinette became a proof of principle for both of the above-mentioned prototype convection-style target cells, as well as the first of the Stage-I target cells that is undergoing testing at the time of this writing.

In short, the work presented here provided the basis for designing the high-performance Stage-I and Stage-II target cells that will be used in future JLab experiments. The proof-of-principle began with the cell Antoinette, and continued with the two prototype convection-style target cells (both of which also contained roughly 3 STP liters of ^{3}He). The first actual Stage-I target cell looks very promising in early tests, providing further confidence in the design of the Stage-II target cells that will soon be produced.

1.2 Incorporating Metal End Windows

Prior to the work described here, there was only very limited experience with spin-polarized noble gases in cells containing metal. The reason is that the introduction of any new material generally causes spin relaxation greatly in excess to that caused by the walls of the glass container. The target-cell design shown in Fig. 1.1, however, incorporates metal end windows so that even a fairly intense electron beam will not cause the target cell to rupture, even after multiple weeks of operation. One of the important achievements of the current work was the development of a technique for producing metal surfaces that induce spin relaxation at an acceptably slow rate. We further have demonstrated a means for making transitions between glass and metal, even when operating at the high pressures used in our polarized ^{3}He targets. We describe next why metal end windows based on the techniques demonstrated here are likely to have an almost negligible effect on the overall performance of our target cells.

Relaxation times measured by pure GE180 target cells and GE180 test cells with metal have provided enough data for us to extract spin-relaxation rates due to metal surface and calculate the additional relaxation rates that will be introduced by metal end windows. The measured lifetime of ProtovecI, a pure GE180 cell, was 26.52 hr and the measured lifetime of Goldfinger180, a vertical GE180 test cell with gold-coated OFHC copper tube, was 12.4 hr. With the equation $\Gamma_{wall} = \rho S/V$ and the geometrical properties of cells, the relaxivity ρ of GE180 and gold surface can be extracted. Assuming the metal end windows have 1" diameter and 1 cm length and using the same value of volume as that of ProtovecI, we can estimate the relaxation rate due to the addition of metal end windows will be 1/98 hr^{-1}. If we double the volume for the upcoming SBS G_E^n experiments to compensate for the higher relaxation rate due to higher electron beam current, the relaxation rate introduced by metal will further drop to 1/196 hr^{-1}. Thus, metal end windows are likely to only cause negligible spin-relaxation rate for the purpose of the experiments planned.

During the 6 GeV era where only 10-15 μA was used, glass end windows were already running into risk of rupturing after 4-6 weeks of being exposed to electron beam. If it was solely due to radiation damage, one can expect the glass windows to rupture after roughly a week of being used in electron beam of 60 μA, which will be far from enough for the experiments to complete. On the other hand, experience at JLab suggests that even very thin metal windows should still be able to survive the electron beams. As a an example, aluminum as thin as 2 mils has been routinely used in JLab without failing. The fact that metal end windows will conduct heat better further suggests that they will be more suitable for experiments planned for the 12 GeV era. Copper test pieces with thin hemispherical end caps using OFHC copper and aluminum will be made into test cells based on the design shown in Fig. 1.1 before the planned experiments are conducted.

1.3 Summary

We have confidence that convection style targets with metal end windows will not only give high ^{3}He polarization in both PC and TC, but also survive the high electron beam currents planned for the future experiments. The work done in this thesis has demonstrated that the additional spin-relaxation rate due to surfaces in metal end windows will be negligible for our purposes and has provided techniques for connecting metal end windows to glass. All the tests so far have been performed on test cells with metal tubes. Before a target cell with next-generation design can be produced, tests exploring techniques for making hemispherical metal end caps should be carried out. However, with techniques established so far, we believe the next-generation design will be used to great success in the upcoming experiments planned for the 12 GeV era.

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