LASER DRIVEN H/D TARGET AT MIT-BATES

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A polarized hydrogen/deuterium internal target is being developed at MIT to be used in the South Hall Ring (SHR) at the MIT-Bates Linear Accelerator Center. In principle such a target can yield a higher figure of merit than that of the conventional atomic beam source (ABS) because of its greater thickness. Potassium vapor is optically pumped by circularly polarized laser light, tuned to the 770 nm D1 transition, in a spherical spin-exchange cell which is optimized to reduce recombination and depolarization. The angular momentum is then transfered to the H/D atoms through spin exchange collisions. Even in the 100 mTesla holding field needed to overcome radiation trapping and efficiently pump potassium, the large number of hydrogen collisions in the spin-exchange cell enhances the hyperfine interactions and drives the system to spin temperature equilibrium, yielding high nuclear polarization without RF transitions. A description of the target with preliminary measurements of hydrogen dissociation and atomic polarization has been reported elsewhere[1]. An update of these results based on a new spin-exchange cell will now be presented. The spin-exchange cell is still in the process of being optimized.

1. Introduction

In the last decade, several groups[2,3,4] have demonstrated the feasibility of polarized H/D targets by spin-exchange optical pumping as an alternative to the established atomic beam source (ABS) technology. Because it is actively pumped, the laser driven target (LDT) can be up to 25 times thicker, compensating for the smaller polarization and allowing for a potentially higher overall figure of merit.

A great candidate for the use of such a target is the new BLAST detector currently being installed in the South Hall Ring at the MIT-Bates Linear Accelerator Center. This large acceptance spectrometer is designed to study the spin-dependent electromagnetic responses of few-body nuclei using a longitudinally polarized electron beam at energies up to 1 GeV. We are

developing a LDT for the experiment "A precision measurement of the charge radius of the proton" (RpEX)[5] at BLAST. Our goal is to achieve a 60% dissociation fraction and 50% polarization at a hydrogen flow rate of 2×10^{18} atoms/s, which corresponds to a thickness of 2.8×10^{15} cm^{-2}.

2. Spin Exchange Optical Pumping

The spin-exchange optical pumping technique involves the transfer of angular momentum from a circularly polarized laser beam to potassium and subsequently to atomic H/D via spin-exchange collisions. The potassium $4\,^2S_{1/2}$, $m_e = -1/2$ ground state is excited by a σ_+ photon to the $4\,^2P_{1/2}$, $m_e = +1/2$ state, which decays back to both ground state levels, populating the $m_e = +1/2$ state over time. A strong 100 mTesla holding field helps to overcome the radiation trapping effect in order to reach high optical pumping efficiency. The spin is transferred to the H/D atoms through spin exchange collisions. Even though the nuclear and atomic spin states decouple in the high magnetic field, the large number of H-H collisions enhance the hyperfine interaction allowing the atomic and nuclear states to reach spin temperature equilibrium (STE)[6]. At this point the nuclear polarization is the same as the atomic polarization for H, and even larger for D vector polarization. STE has been demonstrated in a laser driven target by the Erlangen group[3] for hydrogen using a Breit-Rabi polarimeter, and by the Argonne group[4] for deuterium using the reaction $d + {}^3H \rightarrow n + {}^4He$. Such a target has been used for the first time in a nuclear experiment at IUCF[7].

3. Experimental Setup

The optical pumping occurs in a 5 cm diameter spherical Pyrex spin-exchange cell, combined with a 5 cm transport tube leading to the target cell. The spin-exchange cell is optimized to minimize the number of wall bounces, while having a large enough dwell time to reach STE, as shown in Table 1. It is coated with drifilm to minimize recombination and depolarization effects of wall collisions. Hydrogen or deuterium gas is fed through a flow control unit into an RF dissociator connected to the spin-exchange cell through a 1 mm restriction. Potassium vapor is also introduced to the spin-exchange cell from a heated ampoule. The whole spin-exchange cell and transport tube is kept above 180°C in a forced air oven to prevent potassium from condensing on the surface. The spin-exchange cell is driven with a 3 W Ti:Sapphire standing wave laser. Laser diagnostics include

power meters before and after the spin-exchange cell, a wave meter, and a spectrum analyzer. Because of geometry constraints, two polarization-preserving mirrors are needed to periscope the 3 cm expanded beam into the spin-exchange cell. The spin-exchange cell/transport tube sits on top of a 40 cm long 1.25 cm diameter storage cell, also coated with drifilm. The 6 mm entrance aperture ensures that the atoms reach STE.

Table 1. Calculated parameters for a single H atom in the LDT at 1×10^{18} atoms/s.

	sin-exchange cell	transport tube	storage cell
wall collisions	640	96	768
K-H collisions	11.1	0.4	3.0
H-H collisions	443.9	25.0	119.9
dwell time (ms)	6.8	0.38	3.9
spin temp const (s)	7.5×10^{-5}		

The polarimeter is precisely aligned with metal bellows to either of two sampling holes placed at 90° to the target cell entrance. These bends in the atomic path verify that polarization and degree of dissociation are being measured from the target cell and not directly from the spin-exchange cell. The polarimeter consists of two chambers, the first chamber has a 1 Tesla, 15 cm long permanent sextupole magnet, a shutter for background measurement, and 3 alignment apertures (blank conflat gaskets drilled with 3 mm holes) for beam collimation and differential pumping. The second chamber has a 20 Hz chopper and a Balzers Prizma quadrupole mass analyzer (QMA) which was modified to output a pure analog signal. A 300 l/s ion pump in each chamber and a NEG pump in the final chamber keep the pressure at 5×10^{-9} Torr with 1 sccm of gas flow.

The polarimeter is used to measure both the dissociation and polarization. The degree of dissociation is obtained by measuring the percentage drop in the H_2 signal as the RF dissociator is turned on. The subtracted background is measured with the polarimeter misaligned instead of the shutter closed, to include background from the target chamber (10^{-5} Torr), where the contribution is the greatest. Similarly, the polarization is measured by the fractional rise or fall in the H_1 signal when the laser shutter is opened to allow optical pumping. The laser helicity is switched by flipping the waveplate and tuning the laser frequency.

4. Results

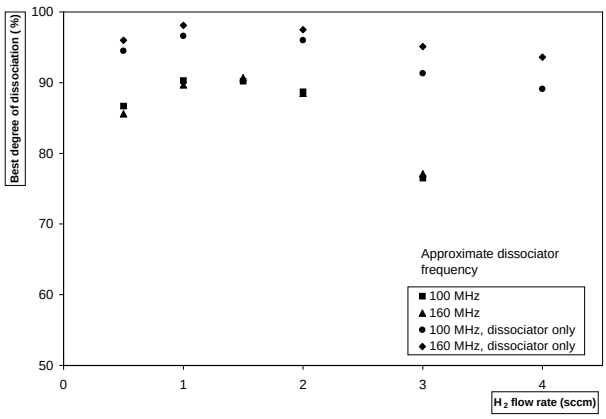

Figure 1. Comparison of the degree of dissociation directly from a dissociator with a 1mm diameter aperture (diamonds,circles) and the degree of dissociation at the target cell (triangles,squares), operated at two RF frequencies.

Preliminary results reported earlier[1] show a high degree of hydrogen dissociation from a dissociator with a 1mm diameter exit aperture. A spin-exchange cell with a 1mm diameter aperture has been constructed and is currently being tested. Fig. 1 shows the degree of dissociation with the complete system (up to 90% with flow rates in excess of 10^{18} atoms/s) at room temperature. The degree of dissociation directly from a dissociator with a 1mm diameter aperture is shown for comparison. In temperature dependence tests Fig. 2, the dissociation stayed above 80% after heating the spin-exchange cell oven above 200°C. Fig. 3 shows a measurement of the polarization of 36% after atomic signal background subtraction, where the polarization is given by the change in the atomic signal divided by the unpolarized signal (laser shutter closed). We expect that the background is due to uncollected hydrogen atoms when hydrogen molecules are ionized at the QMA. Potassium polarization, and ultimately the hydrogen polarization, can be increased through the use of an Electro-Optic Modulator (EOM). The polarization reported here is without the use of an EOM, which we plan to install in the near future. The Figure of Merit (FOM) is

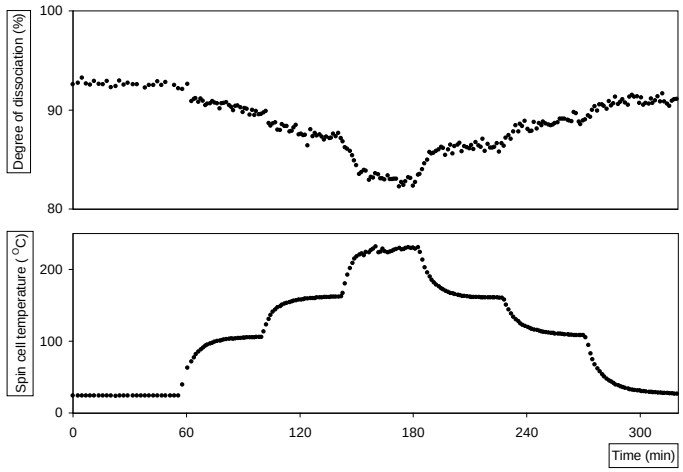

Figure 2. Spin-exchange cell temperature dependence of dissociation at the target cell.

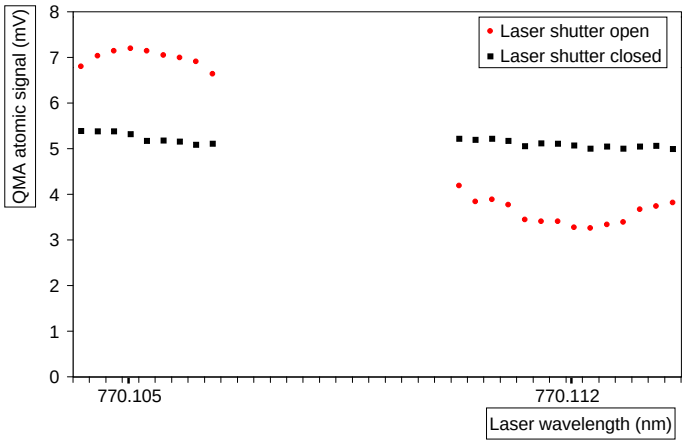

Figure 3. The Ti:Sapph laser is scanned over the potassium D1 transition, first right circular polarized, and the left circular polarized.

a measure of the performance of the target, and Fig. 4 shows the hydrogen FOM during the process of optimization. From Section 1, the goal for the FOM is 1.8×10^{17}atoms/s.

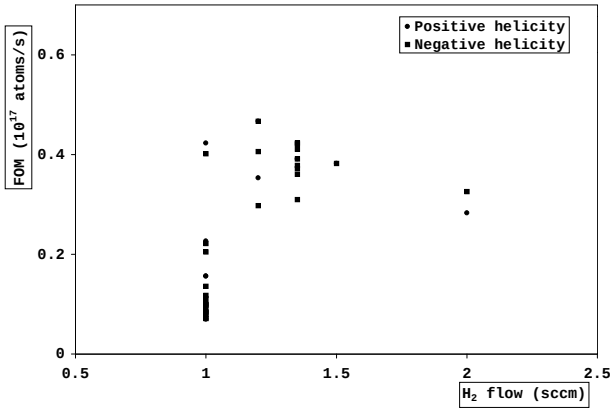

Figure 4. Preliminary target FOM results, where FOM = flow×(degree dissociation× polarization)^2.

5. Conclusion and Outlook

We have finished the design and construction phase of a Laser Driven Target and have produced high atomic polarized hydrogen atoms at flow rates exceeding 10^{18} atoms/s, which have been calculated to be in spin temperature equilibrium. Future work will include the installation of an electro-optic modulator system into the pump beam from the Ti:sapph laser, investigating methods to improve the spin-exchange cell coating, and the completion of a potassium vapor monitor for the spin-exchange cell based on the Faraday rotation technique[8]. The target is planned to be used at the MIT-Bates Linear Accelerator Center for fundamental few-nuclei experiments, such as RpEX.

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References

1. C. Crawford et al., in *Proceedings of the International Workshop on Polarized Sources and Targets*, Indiana, USA (2001).
2. M. Poelker et al., *Nucl. Instrum. Methods* A **364**, 58 (1995).
3. J. Stenger et al., *Phys. Rev. Lett.* **78**, 4177 (1997).
4. J. A. Fedchak et al., *Nucl. Instrum. Methods* A **417**, 182 (1998).
5. MIT-Bates PAC Pr. 00-02, spokespersons: H. Gao and J. R. Calarco.
6. T. Walker, L. W. Anderson, *Nucl. Instrum. Methods* A **334**, 313 (1993).
7. R.V. Cadman et al., *Phys. Rev. Lett.* **86**, 967 (2001).
8. J. Stenger et al., *Nucl. Instrum. Methods* A **384**, 333 (1997).