DEVELOPMENT OF A POLARIZED DEUTERIUM TARGET BY SPIN EXCHANGE WITH OPTICALLY PUMPED K*

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ABSTRACT

The development of a polarized internal target at an electron storage ring is of great interest for studies in nuclear physics. The deuterium nuclei acquire polarization via the hyperfine interaction after electron spin exchange with optically pumped potassium vapor. A high power laser which covers the entire doppler width and hyperfine splitting of the $2S_{1/2} - 2P_{1/2}$ transition in potassium has been developed. Spin relaxation rates for potassium on various wall coatings have been measured. A dry-film surface has been shown to preserve polarization (> 100 bounces), be long-lived at elevated temperatures, and to be efficient at preventing deuterium recombination.

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INTRODUCTION

Recently there has been much interest in the development of sources of polarized nuclei for use in electron scattering experiments. Particularly, in this lab, interest has centered around the prospect of observing tensor polarization in electron-deuteron elastic scattering. This measurement would allow the separation of the charge and quadrupole form factors for the deuteron and address some of the most fundamental questions in nuclear physics as described by Holt. [1] Recognizing the manyfold advantages of performing this and other scattering experiments in a storage ring, [1,2] we have been developing a source of polarized deuterium atoms suitable for use as an integral target.

Various methods exist to produce a vapor of polarized deuterium nuclei. The conventional atomic beam method combined with storage cells [3] may yield target thicknesses up to 10^{14} nuclei/cm². We have proposed using optical pumping spin-exchange in order to achieve an order of magnitude greater target thickness [2,4].

The principle behind the optical pumping spin exchange method of nuclear polarization is as follows: 1) First, angular momentum from a photon beam is transferred to a intermediate, e.g. an alkali atom. 2) Second, the electron polarization of the alkali is transferred during a spin exchange collision to the deuterium atom. 3) Third, the hyperfine interaction couples the electron and nuclear spins of the deuterium atoms, such that the nucleus in turn becomes polarized. Eventually, after a few such spin exchange collisions both the electron and nucleus of the deuterium atom will become spin polarized. This method has been used to study hyperfine structure of hydrogen isotopes [5] and recently to produce spin-polarized hydrogen in a static cell [6].

The technological difficulties in attaining a high polarization of deuterium atoms without a large background of undissociated D_2 or other species are primarily twofold. First, one must be able to achieve a high polarization in the optically-pumped alkali vapor. Due to their spectral brightness, lasers are the obvious choice as photon sources. However, typically the spectral distribution from a laser may only cover $\sim 1\%$ of the doppler profile of the absorption line. Methods developed to combat the spectral overlap problem include: 1) introduction of a buffer gas to induce velocity changing collisions, [7] 2) power broadening of the absorption line, [8] 3) tailoring the spectral output of the laser to match the doppler width [9]. It is the third method we have used to achieve complete doppler coverage. The choice of potassium vapor as the optically-pumped alkali alleviates the additional spectral overlap problem due to hyperfine splitting, which would be present in other alkalis, since its optical hyperfine structure, 462 MHz, lies within the 1.0 GHz doppler width. The second technological challenge is maintaining the polarization, i. e. finding a surface which does not depolarize deuterium or potassium and also does not recombine deuterium at the elevated temperatures ($\sim 200^\circ \text{C}$) required. Previous findings with Na indicate that "dri-film" may be a good surface in terms of alkali depolarization [10].

Here we report on progress made toward the achievement of a polarized deuterium target using spin-exchange with optically pumped potassium vapor.

EXPERIMENTAL

Two types of measurements have been performed on the experimental apparatus described below and shown in fig. 1. They are 1) spin relaxation

rate, determined by measurement of the characteristic risetime of transmission as a function of pump laser intensity 2) D atom recombination, determined by measurement of dissociation fraction as a function of cell condition.

The lightsource employed in these experiments was a multimode standing wave dye laser CR559-01 pumped by a SP 171 Ar^+ laser operating on all lines. In addition to the standard 3-plate birefringent filter, the laser cavity was fitted with a thin (0.5 mm, 20% R) and a thick (5.0 mm, 30% R) etalon to give output in three adjacent longitudinal modes separated by 300 MHz. Walk-off losses in the thick etalon are severe [11] but can be avoided by temperature tuning the thick etalon to adjust the laser frequency to the potassium D1 resonance line. Frequency stable operation within the 1.0 GHz doppler width can be maintained for hours, whereas jitter between the three allowed longitudinal modes is statistical and occurs on a timescale ~ 20 μs . Wobbling the PZT mounted fold mirror at a mechanical resonance (~ 70 kHz) serves to further smear out the picket fence nature of the laser output. Using Pyridine 2 dye, typical output in this configuration was 200 mW @ 770 nm when pumped with 3.0 W all lines visible from the Ar^+ laser.

The laser beam was sent through an acousto-optic modulator (Isomet 1205-C) to produce pulsed light (risetime ~ 25 ns) and circularly polarized with a quarter wave plate. Neutral density filters were used to alter the pump intensity. A silicon photodiode was used to detect the transmitted light.

Design parameters for the mixing cell have been described in detail previously [4] and will not be repeated here. Briefly, the cell consists of a cylinder with optical windows on each end and three holes along the sides. Two holes near one end serve as inlets for potassium and dissociated deuterium, respectively. Near the other end, the third hole provides the

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Scheduled Completion Date - Baseline: _____ Estimated Cost at Completion - Baseline: _____
- Current: _____ - Current: _____

Project Progress During Month:
project objectives or technical

Variances:
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Open Items:

Project Manager's Assessment and Forecast:

Summary	Satis-	Minor	Major
<u>Assessment:</u>	<u>factory</u>	<u>Concern</u>	<u>Concern</u>

Cost

Schedule

Technical

Overall

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escape for the polarized D atoms. Diagnostics for the dissociation fraction consist of a rotating chopper and a quadrupole mass spectrometer located under the exit hole. The temperatures of the K pot, D nozzle, mixing cell, and spout are all independently controlled.

For the experiments described here, the stainless steel surface was changed by placing a coated sleeve with three appropriately aligned holes inside the mixing cell. The coating procedure was described previously [12].

DATA AND ANALYSIS

In the simplest model of the optical pumping process, a three level system shown in Fig. 2, the time dependence of the transmitted light is governed by the population in the absorbing state A.

$$\frac{dN_A}{dt} = - (P_{AB} + \lambda_{AB}) N_A + \lambda_{BA} N_B \quad (1)$$

where P_{AB} = optical pumping rate and λ_{AB} are the relaxation rate. Assuming that $\lambda_{BA} = \lambda_{AB} \equiv \lambda$ and $P_{AB} \equiv P$, it can be shown that

$$N_A = \left(\frac{N}{P + 2\lambda} \right) \left(\lambda + \frac{P}{2} e^{-(P + 2\lambda)t} \right) \quad (2)$$

The characteristic risetime τ is then given by

$$\frac{1}{\tau} = P + 2\lambda = \frac{1}{T_{\text{pump}}} + \frac{2}{T_{\text{relax}}} \quad (3)$$

If we further assume that $\frac{1}{T_{\text{pump}}} \approx kI$ then measurement of $1/\tau$ for various pumping intensities, I , will yield T_{relax} .

A typical analysis is shown in Fig. 3. Results for a variety of

surfaces are given in Table 1. The durability of the surface as a function of operating time is shown in Fig. 4.

Measurements were also made of the D_2 dissociation fraction as a function of operating temperature of the cell and K pot for a dri-film surface. The results, shown collectively in Fig. 5, indicates that the dissociation fraction increases as a function of cell temperature at a given K pot temperature. This suggests that condensation of K on the mixing cell walls provides a surface for efficient D atom recombination, and that cold spots in the system are a problem.

CONCLUSIONS AND FUTURE DIRECTIONS

Dri-film appears to be a good surface for these applications. Depolarization probability of potassium on dri-film is shown to be $< 1/100$. In addition, the dissociation fraction measured after transit thru the cell remains high, $> 70\%$, at the highest cell temperatures tested, so decomposition of dri-film does not appear to be a problem.

Improvements to be made to the system include 1) doubling laser power with a second dye laser, 2) optimizing thermal conductivity by incorporating an all glass system 3) using an NMR technique to probe the polarization of the K and D atoms.

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Table 1. Spin Relaxation Rates

Surface Condition	T_R (ms)
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Stainless Steel	0.006
Stainless Steel + Ar buffer gas	0.064
dri-film on Cu	1.0 - 1.4

Figure Captions

- Figure 1 Schematic of the experimental apparatus
- Figure 2 R is the optical excitation rate from state A to C. Γ_A and Γ_B are radiative decay rates from C to the two lower levels A and B respectively. The pumping rate, P_{AB} , referred to in the text = $R \frac{\Gamma_A}{\Gamma_A + \Gamma_B} \propto kI$. λ is the relaxation rate between A and B.
- Figure 3 Observed risetime in transmission vs laser intensity. eq. (3). Intercept is $2/T_{\text{relax}}$.
- Figure 4 Dissociation fraction of D_2 vs potassium pot temperature, on a stainless steel cell coated with dri-film. $\bullet$ = 2 coats of dri-film $T_c = 210^\circ \text{C}$, $\square$ 2 coats of dri-film, $T_c = 224^\circ \text{C}$.
- Figure 5 Spin relaxation rate vs operating time in a Cu sleeve coated with dri-film.

Fig. 1

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Fig. 2

Fig. 3

Fig. 4

Fig. 5