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A HIGH FIELD OPTICAL-PUMPING SPIN-EXCHANGE POLARIZED DEUTERIUM SOURCE

K. P. COULTER, R.J. HOLT, E.R. KINNEY, R.S. KOWALCZYK, M. POELKER, D.H. POTTERVELD, L. YOUNG, B. ZEIDMAN
Argonne National Laboratory
Argonne, IL 60439
USA

D. TOPORKOV
Budker Institute for Nuclear Physics
Novosibirsk, Siberia
RUSSIA

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ABSTRACT

Recent results from a prototype high field optical-pumping spin-exchange polarized deuterium source are presented. Atomic polarization as high as 62% have been observed with an intensity of 6.3×10^{17} atoms$\cdot$sec^{-1} and 65% dissociation fraction.

1. Introduction

In the last five years there has been a rapid growth in interest in the use of dilute polarized gases as polarized nuclear targets in particle storage rings. Experiments using or proposing the use of internal polarized gas targets exist for accelerators at Novosibirsk [1], Serpukov [2], Indiana [3], MIT-Bates [4], NIKHEF [5] and Saskatoon. This has driven the search for intense spin-polarized beams of atoms. We report here an update of results for a high intensity source of polarized deuterium that is based upon spin-exchange optical pumping in a high magnetic field. In the optical-pumping spin-exchange process alkali atoms are polarized by optical pumping and this polarization is transferred to deuterium atoms during alkali-deuterium spin-exchange collisions. The first results from this source were presented in Reference 6. Results from conventional atomic beam sources and an ultra-cold source are presented elsewhere in these proceedings.

2. Experimental Technique

The principle of spin-exchange optical pumping has long been known [7]. However, previous attempts [8] to develop this idea into a practical source of atoms were limited because radiation trapping constrained the density of optically pumped alkali. In Reference 6 it was shown that performing spin-exchange optical pumping in a high magnetic field can overcome this radiation trapping problem. In a high magnetic field this process involves primarily the electron spin. In terms of the alkali polarization P_A, the deuterium atomic polarization P_e obeys the equation

$$P_e = \frac{\gamma_{SE}}{\gamma_{SE} + \gamma_R} P_A \left(1 - e^{-(\gamma_{SE} + \gamma_R)t}\right) \tag{1}$$

where $\gamma_{SE} = \langle \sigma_{SE} v \rangle N_A$ is the spin-exchange rate and γ_R is the deuterium spin-relaxation rate. The spin exchange rate depends on the alkali number density N_A, the spin exchange cross section σ_{SE}, and the average deuterium-alkali relative velocity v. The spin-relaxation rate depends on the collisions with the cell walls and loss of polarized atoms out of the cell. At low magnetic field radiation trapping limited the number density of alkali that could be effectively optically pumped, limiting the spin-exchange rate to approximately 300 s^{-1}. However at high magnetic field this radiation trapping limit occurs at higher alkali number densities [9] because of increased spacing between the σ and π light absorption due to Zeeman splitting. Thus, at high magnetic field, a higher optical spin exchange rate can be maintained at high alkali polarization.

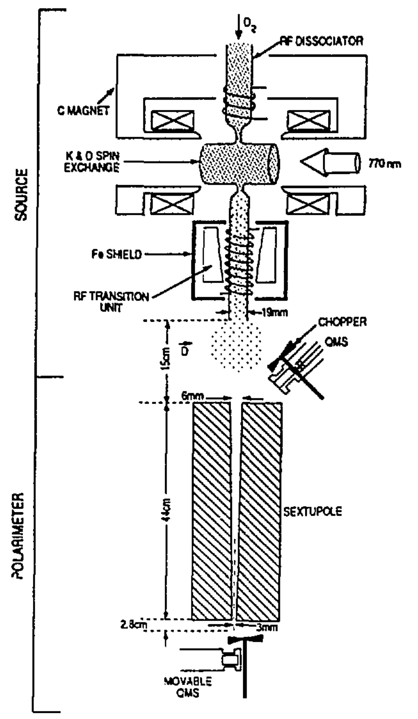

Figure 1. Schematic diagram of the polarized source and polarimeter.

The optical-pumping spin-exchange apparatus is shown schematically in Figure 1. Only a short description is given here; the experimental arrangement is described in more detail in reference 1. Significant differences are noted in this text. Potassium vapor in a drifilm-coated Pyrex spin exchange cell is optically pumped with 770.1 nm light from a Ti-sapphire laser. Deuterium atoms flow from a dissociator through this cell. Both species of atoms exit the cell through a 3.1 mm diameter hole and travel down a Pyrex transport tube into a spin polarimeter.

The spin polarimeter consists of a permanent sextupole magnet followed by a movable quadrupole mass analyzer (QMA). A small fraction of the deuterium atoms flows from the transport tube into the front aperture of the sextupole. The sextupole focuses spin-up atoms and defocuses spin-down atoms. Deuterium atoms that exit the sextupole along its axis are detected by the QMA. The QMA can differentiate atoms with

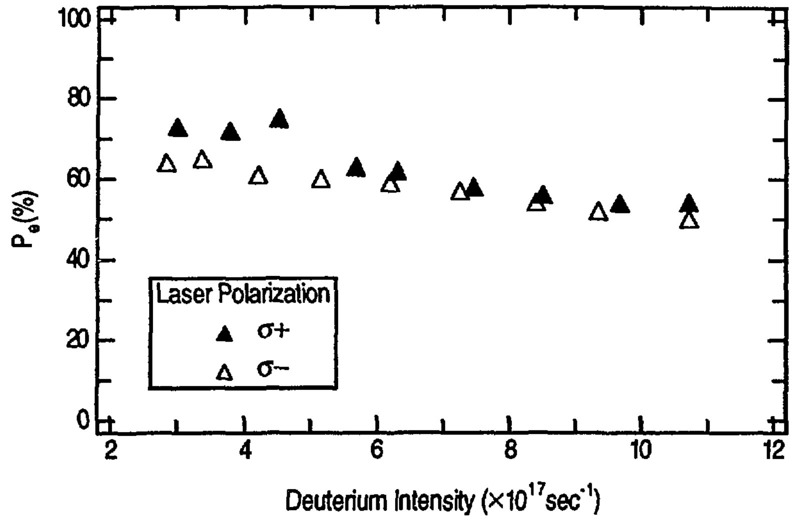

Figure 2. Deuterium polarization as a function of total deuterium intensity for both orientations of laser polarization.

atomic masses in the range of 1-4, so that the background signal of molecular deuterium is negligible. (This also allows the determination of the fraction of atoms that are in atomic form and any molecular hydrogen contamination.) Ambient atomic deuterium background is removed by chopping the beam exiting the sextupole and using a lock-in amplifier to detect only the chopped signal. The atomic polarization of the deuterium atoms is determined by the change in the QMA signal when the laser light is turned on and off. (This use of a QMA is the most substantial difference in the polarimeter from the work reported in Reference 1 which used a compression tube.)

3. Results

The performance of the high field optical-pumping spin-exchange source has been investigated over a large part of the accessible parameter space. The atomic deuterium polarization has been measured as a function of the deuterium flow, the magnetic field, the laser power and the potassium density. Figure 2 shows the results for atomic deuterium polarization as a function of the total intensity of deuterium atoms. These data were taken at a magnetic field of 4.4 kGauss and with approximately 3.0 watts of laser power incident on the cell. The average dissociation fraction (Df) was 60% and reached a minimum of 51% at the highest intensities. The temperature of the potassium source was 188°C corresponding to an approximate density in the spin exchange cell of $(1.5 \pm 0.5) \times 10^{12}$ atoms-cm^{-3}. This density is optimum for our cell. Higher densities produce slightly higher deuterium polarization at the cost of increased potassium contamination. Using

$\langle \sigma_{SE} v \rangle = 1 \times 10^{-9}$ $cm^3 \cdot s^{-1}$, at this density the spin exchange rate is approximately $\gamma_{SE} = 1500 \pm 500$ sec^{-1}. Taking $P_A = 1$ and $P_e = 0.62 \pm 0.03$ at 6.3×10^{17} atoms $\cdot s^{-1}$, an upper limit on γ_R is determined to be $920 \pm 300\, s^{-1}$.

The deuterium polarization was measured as a function of intensity for different incident laser powers. There was less than a 2% absolute change in polarization when the incident power was changed from 3.0 to 1.5 watts. The magnetic field was also varied. At lower intensities ($2-5 \times 10^{17}$ atoms $\cdot$ sec^{-1}) the deuterium polarization improves significantly between 1.2 and 2.2 kGauss. Above 2.2 kGauss only minor improvement is observed. At higher intensities , only minor improvement is observed with increasing magnetic fields above 1.1 kGauss. As he suppression of radiation trapping is not expected to increase at these higher fields; these effects may be due to decreased loss of polarization during wall bounces [10].

4. Conclusions

The performance of the high field optical-pumping spin-exchange polarized deuterium source has been examined at high deuterium flows and for varying potassium densities, laser powers, and magnetic fields. The figure of merit neglecting any potassium contribution is a factor of two greater that the previously published results [1] ($(P_e Df)^2 I = (0.62 \times 0.65)^2 \times 6.3 \times 10^{17} = 1.0 \times 10^{17}$). Given this performance, preparations are under way to install this source at the VEPP-3 storage ring in Novosibirsk to continue the measurements reported in Reference 1.

It is noted that the present polarimeter is able to measure only the electronic polarization of the deuterium. A group at the University of Wisconsin has constructed a polarimeter based on the known tensor analyzing power of the d-t reaction. This polarimeter is presently being fitted to our apparatus. This will enable us to directly measure the nuclear polarization of the source and test the efficiency of the RF transitions required by the high field technique. Additionally, it has been suggested [11] that deuterium-deuterium spin exchange collisions are numerous enough so that even at high magnetic fields a significant amount of polarization may be transferred to the D nucleus. This polarimeter can test this hypothesis.

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