

L. YOUNG, R. J. HOLT, M. C. GREEN AND R. S. KOWALCZYK

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Physics Division, Argonne National Laboratory, Argonne, IL 60439 USA

A novel laser-driven polarized source of hydrogen and deuterium which operates on the principle of spin exchange optical pumping is described. The advantages of this method over conventional polarized sources for internal target experiments are presented. Technological difficulties which prevent ideal source operation are outlined along with proposed solutions. At present, the laser-driven polarized hydrogen source delivers  $8 \times 10^{16}$  atoms/s with a polarization ( $P_2$ ) of 24%.

## 1. INTRODUCTION

The development of high flux sources of polarized hydrogen and deuterium is of great importance for studies of spin-dependent structure in nuclei. Proposed experiments utilize high energy electron scattering from internal polarized gas targets as a probe of nuclear structure.<sup>1,2</sup> The classical method to obtain usable target thicknesses ( $10^{13} - 10^{14} \text{ cm}^{-2}$ ) is to feed the output of a polarized source into a storage cell.<sup>3</sup> Various options exist for the polarized source. The two being actively considered are the conventional atomic beam source<sup>4</sup> and the laser-driven source<sup>5</sup> to be described here.

The laser-driven polarized source is based on the principle of spin exchange optical pumping.<sup>6</sup> In this method, photon angular momentum is transferred to an intermediate alkali atom, which, through spin exchange collisions, will polarize the electron of the hydrogen/deuterium atom. The nucleus becomes polarized, since at low magnetic fields, the electronic and nuclear spins are coupled by the hyperfine interaction. Compared to conventional sources the key advantages for internal target applications are: 1) the flux from the source is expected to be limited only by laser power, 2) the source emittance is easily tailored to meet storage cell requirements, 3) low-background gas load to the storage ring.

## 2. EXPERIMENTAL

Figure 1 shows the prototype laser-driven polarized hydrogen/deuterium source. An  $\text{Ar}^+$  - pumped standing wave dye laser operating with Pyridine 2 dye provides the 770 nm radiation required to optically pump the D1 line of potassium (K). The spectral density of the laser is tailored to match the doppler-broadened absorption profile of the K vapor ( $\approx 1.5 \text{ GHz}$ ) using an

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electro optic modulator (EOM). The "tailored" laser output is sent through a linear polarizer, circular polarizer and then into the spin exchange cell.

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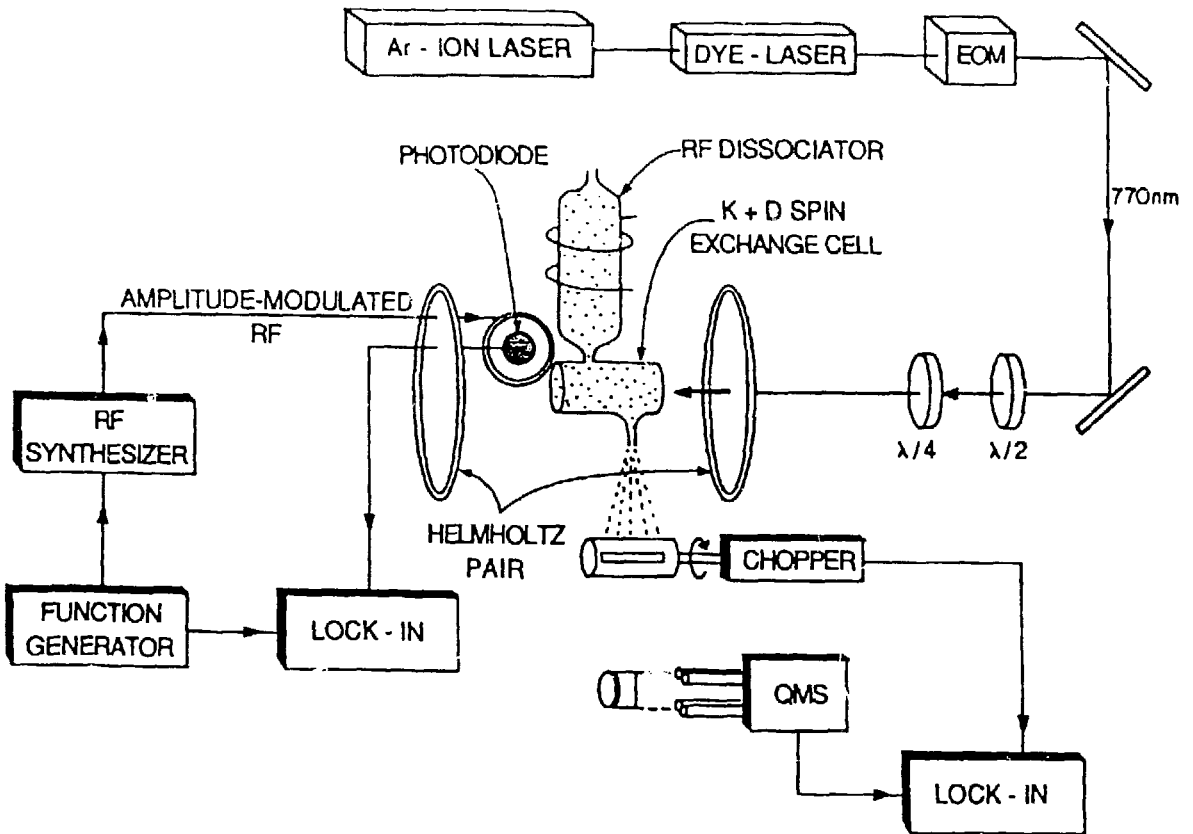


Figure 1 Schematic diagram of the laser driven polarized source of H/D.

The spin exchange cell is constructed of pyrex as an integral unit with the rf dissociator (H/D source) and the K reservoir. The cell interior is coated with a polarization preserving material, dri-film.<sup>7</sup> The cell is placed in a static field of  $\sim 10$  Gs. The flux (density) of the H/D atoms is controlled by a mass flowmeter in conjunction with a servo-driven needle-valve. The density of the K atoms is independently controlled through the reservoir temperature. The entire cell is enclosed in a copper oven and heated to  $\sim 230^\circ$  C to prevent alkali condensation. Typical K/H density ratios are 1 - 10%.

The usable flux of H/D atoms is determined through a combination of measurements. First, the total flow of  $H_2/D_2$  is measured at the input of

the rf dissociator as described above. Since the entire flow through the rf dissociator is potentially useful (excluding losses through recombination, chemical reaction etc.), it is only necessary to measure, at the output, the fraction of  $H_2/D_2$  which remains dissociated. This is done using a mechanical chopper and quadrupole mass spectrometer (QMS) in combination with a lock-in amplifier. The molecular ( $H_2$  or  $D_2$ ) intensity is measured with the rf to the dissociator first turned off and then on. The fraction dissociated is simply:  $DF = 1 - I(\text{rf on})/I(\text{rf off})$ . A typical dissociation fraction for a 1000 bounce cell with a well-prepared dri-film surface is 70-80%.

The other important parameter in source characterization is the polarization of the H atoms. This is measured using optically detected magnetic resonance.<sup>8</sup> In this method, the transparency of the K + H sample to the resonance radiation is decreased by inducing Zeeman (depolarizing) transitions with a small coil placed at right angles to the holding field. The decreased transparency causes an increase in resonance fluorescence which is detected by a photodiode as shown in Fig. 1. Both the polarization of the K and the H can be detected in this manner by sweeping the depolarizing rf field over the appropriate frequency range. The depolarizing field is amplitude modulated and the detected fluorescence is processed through a lock-in amplifier in order to reduce noise resulting from laser intensity fluctuations.

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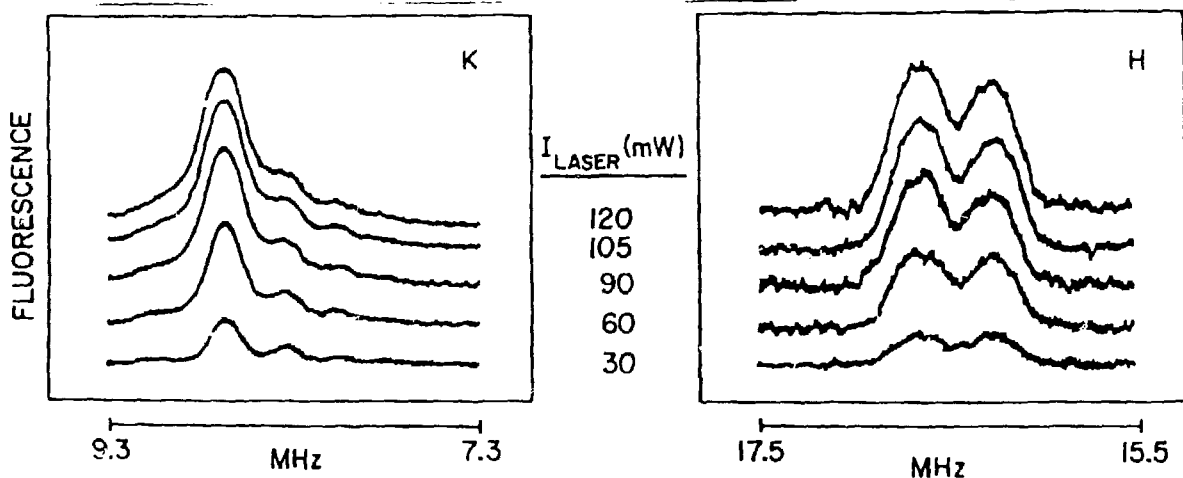


Figure 2 Zeeman transition signals for K (left) and H (right) as a function of incident laser power.

Figure 2 shows a typical family of Zeeman signals for K and H as a function of laser power. From these curves it is possible to determine the polarization of the K and H vapor within the spin exchange cell. The

populations of the magnetic sublevels of both K and H are assumed to be in spin equilibrium, i. e. describable by a spin temperature,  $\beta$ . In this case, the relative state populations ( $n_i = C e^{-\frac{m\beta}{i}}$ ) can be deduced from the Zeeman transition signal strength which is proportional to  $|(F, m | J_- | F, m+1)|^2 g(v) \Delta n$ . The top trace for K shows a vector polarization of 82%, whereas the corresponding trace for H shows a polarization of only 15%.

### 3. RESULTS AND DISCUSSION

The best performance of the prototype source that we so far have achieved is a flux of  $8 \times 10^{16}$  H atoms/s, with a polarization of 30% and a dissociation fraction of 80% through a 4 mm diameter spout. Comparable results are obtained for deuterium. This is within a factor of 5 of the benchmark conventional atomic beam source at Bonn<sup>4</sup> (flux  $\sim 3 \times 10^{16}$  atoms/s, polarization  $\sim 90\%$ , through a  $\sim 7$  mm diameter opening). It is, however, much lower than the design goal of  $4 \times 10^{17}$  atoms/s with a vector polarization of 50%.

The various factors limiting source performance are inter-related. The flux can be easily increased. The polarization can not. The H/D flux is increased by enlarging the inlet hole from the rf dissociator to the spin-exchange cell. The polarization is enhanced by increasing the spin-exchange rate relative to the depolarization rate. The spin-exchange rate is proportional to the K density, which can not be arbitrarily increased due to radiation trapping.<sup>9</sup> The depolarization rate is dominated by collisions with the walls. Our data show that the depolarization probability per wall collision for hydrogen atoms is  $\sim 1/300$ . This is significantly poorer than previously reported results for hydrocarbon surfaces.<sup>6</sup>

### 4. CONCLUSIONS

This is the initial demonstration of a laser-driven polarized source of hydrogen. While not yet up to design goals, the results are encouraging. We expect to be able to improve source performance by: (1) minimizing radiation trapping by careful cell design and alkali selection, 2) developing better surface coatings, 3) increasing laser power.

## 5. ACKNOWLEDGEMENTS

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