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A LASER-DRIVEN SOURCE OF POLARIZED HYDROGEN AND DEUTERIUM

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A novel laser-driven polarized source of hydrogen and deuterium which operates on the principle of spin-exchange optical pumping is being developed[1]. This source is designed to operate as an internal target in an electron storage ring for fundamental studies of spin-dependent structure of nuclei[2,3]. It has the potential to exceed the flux from existing conventional sources[4] (3×10^{16}/s) by an order of magnitude. Currently, the source delivers hydrogen at a flux of 8×10^{16} atoms/s with an atomic polarization of 24% and deuterium at 6×10^{16} atoms/s with a polarization of 29%. Technical obstacles which have been overcome, with varying degrees of success, are: 1) complete Doppler-coverage in the optical-pumping stage without the use of a buffer gas, 2) wall-induced depolarization and 3) radiation-trapping. Future improvements should allow achievement of the design goals of 4×10^{17} atoms/s with a polarization of 50%.

Fig. 1 shows the prototype laser-driven polarized hydrogen/deuterium source. Two Ar+-pumped standing-wave dye lasers operating single-mode with Pyridine 2 dye provide the 770 nm radiation required to optically pump the D1 line of potassium. The spectral density of the lasers is tailored to match the Doppler-broadened absorption profile of the K vapor (≈ 1.5 GHz) using a $LiTaO_3$ electro-optic modulator configured in a travelling-wave mode as a ≈50 ohm transmission line. The EOM is driven by a series of components which are used to generate high-power white noise. The modulated laser lineshape is characterized by an unbroadened carrier peak superposed on a noise-broadened background. The noise-broadened background has a spectral density which is reasonably well approximated by a Gaussian profile. Typically, the EOMs are run at a modulation index of 1.5 where roughly 10% of the power remains in the unbroadened carrier and the bandwidth (HWHM) is determined by the 3 dB roll-off of the amplifier (500MHz). The "tailored" laser output is sent through a linear polarizer, circular polarizer, and expanded to fill the cross-sectional area (4.5 cm^2) of the spin-exchange cell. At an incident intensity of ≈ 15mW/cm^2 a factor of ten enhancement is observed in the density of polarized potassium atoms when the laser is noise-modulated. This can be seen in Fig. 2 where the integrated polarization signal (as described below) is increased ten-fold by noise-modulation.

The spin-exchange cell is constructed as an integral unit with the rf dissociator (H/D source) and the K reservoir. It is placed in a static field of ≈ 10 G and heated to 230° C to prevent alkali condensation. The interior is coated with a polarization preserving material, drifilm[5]. The flux 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. Typically, K densities are $1\text{-}3 \times 10^{11}/cm^3$ and H/D densities are $\approx 10^{13}/cm^3$. The usable flux of H/D atoms is determined by measuring, at the output, the fraction of H_2/D_2 which remains dissociated using a mechanical chopper, quadrupole mass spectrometer, and lock-in amplifier. A typical fraction for a 1000 bounce cell with a well-prepared drifilm surface is 70-80%.

The polarization is measured by optical detection of magnetic resonance transitions between the various Zeeman sublevels[6]. The transparency of the sample to the resonance radiation is decreased by inducing Zeeman transitions with a coil placed at right angles to the holding field. The scheme is shown in Fig.2 and measures polarization for both the alkali and deuterium, assuming a spin-temperature distribution for the populations of the magnetic sublevels: $N(m_F)=N_0\exp(\beta m_F)$. Atomic polarizations of ≥80% are routinely obtained for the alkali, but hydrogen and deuterium polarizations range from 20% to 40%.

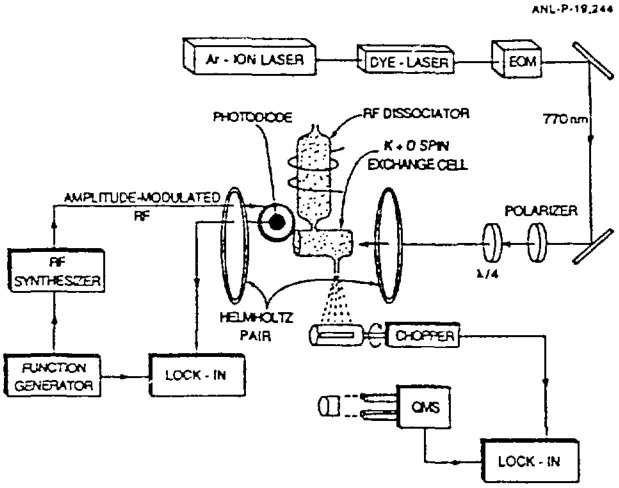

Fig. 1. Schematic of polarized source.

The foremost challenge in the continued development of this source is to enhance the efficiency of polarization transfer from the alkali to the H/D atoms. A rate equation model of the polarization transfer process between two spin 1/2 atoms can be used to understand the the relevant parameters[7]. At steady state, the polarization of the H/D, P_D, can be related to that of the alkali, P_A, by $P_D=P_A k_{se}/(k_{se}+k_d)$, where $k_{se} = n_A v\ \sigma_{se}$ is the spin-exchange rate, and $k_d = \alpha v(1+l/a)/2a$ is the geometry-dependent wall depolarization rate (α=depolarization probability/wall bounce, l=cell length, a=cell radius). For maximum efficiency of polarization transfer, one should maximize n_A and P_A while minimizing α.

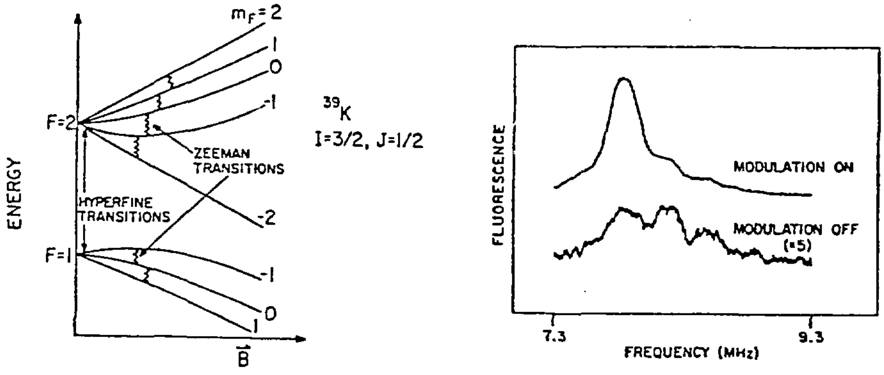

Fig.2. Polarization determination by optical detection of magnetic resonance. Ten-fold enhancement of polarized K density using noise-modulated laser.

For a given alkali and geometry, the maximum alkali density is limited by radiation trapping[8]. A critical density, n_o, can be defined as $(\sigma_0 a)^{-1}$, where the alkali polarization is degraded to ≈ 50%. Radiation trapping tests on closed cells filled with an Ar buffer gas, have shown that the critical density for Na is a factor of two greater than that for K, and thus the attainable k_{se} using Na should be two times larger. With this consideration, we have modified the apparatus to use Na, rather than K as the spin-exchange intermediate. Preliminary results show that even with non-optimal optical pumping conditions for Na (an estimated 75% coverage of the Doppler profile) we were able to observe an increase from ≈25% to ≈ 38% in the deuterium polarization in the spin-exchange cell. Tests with improved laser power and Doppler coverage are currently underway. Future plans include optimization of the cell geometry, using both K and Na as spin-exchange intermediates and (if necessary) studies of wall coatings.

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