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Development of an Optically Pumped Polarized Deuterium Target

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The development of a polarized deuterium target for internal use at an electron storage ring is of great interest for fundamental studies in nuclear physics.[1] In order to achieve the maximum allowable target thickness, 10^{14} nuclei/cm^2, consistent with various constraints imposed by the storage ring environment, a flux of 4×10^{17} polarized atom/s must be provided. This flux exceeds the capability of conventional atomic beam sources by an order of magnitude.[2] We have been developing an alternative source based upon the spin-exchange optical pumping method in which the flux is limited only by laser power.

In this method, the nuclear polarization of atoms with unpaired electrons (e.g. H,D) is achieved by successive spin-exchange collisions with polarized alkali atoms. The electron spin of the atom of interest is initially polarized by the spin exchange-process. Subsequently the electron spin polarization is transferred to the nucleus via the hyperfine interaction. In our case, for a given alkali atom polarization, approximately 5 spin-exchange collisions ($\sigma_{SE} \sim 10^{-14}$ cm^2) are required to obtain the maximum polarization of the deuteron. [1]

This requirement of several spin exchange scatterings dictates the design of suitable containment vessel in which the "reactants", unpolarized D atoms and polarized alkali atoms, can successfully interact multiple times. The additional constraints imposed by the strict vacuum requirements of the storage ring environment dictates that the interaction occur at relatively low pressure ($< 10^{14}$ atoms/cm^3). As a result of these constraints, two technical obstacles arise. Firstly, at these low number densities, the walls of the container play a very important role since wall collisions occur at least 100 times more often than spin exchange collisions. [1] Therefore, the surfaces must inhibit depolarization of both the alkali and the D atom as well as D atom recombination. Secondly, the optical pumping photon beam must cover the entire doppler profile ($\sim$ 1.0 GHz) of the alkali, since no buffer gas is allowed to induce velocity changing collisions.[3]

To address the first of these obstacles, we have investigated the properties of a dri-film surface [4,5], suggested to us by Swenson and Anderson [6]. At low potassium density, the surface appears to be long lasting (> 100 hrs) and to have a spin relaxation probability/collision for potassium of $\sim$ 1/500. The second issue, that of doppler coverage, we have addressed by using two standing wave lasers (CR-599), operating on three adjacent longitudinal modes. In addition, the fold mirror is mounted one a fast PZT (35 kHz) to smear out the laser spectrum.

The polarization of the K, H, or D atoms can be measured by optical detection of magnetic resonance transitions. In this technique, optical pumping of the alkali in a weak B field produces a polarized ensemble with very unequal populations in the magnetic sublevels. When the alkali spin polarization is decreased by applying a radio-frequency field at a Zeeman transition frequency, the transparency of the sample to the optical pumping light is decreased. This can be monitored also as an increase in fluorescence from the sample. By scanning the applied RF frequency and

observing the increased fluorescence, the relative populations in the magnetic sublevels can be deduced using a spin temperature model. [7] The polarization of the spin exchange partner, H or D, can also be detected since it communicates with the alkali through spin-exchange. The detection is made simpler by modulating the amplitude of the applied RF and use of a lock-in amplifier to selectively detect only the increased fluoresence occuring at the modulation frequency. The apparatus is shown in Fig. 1.

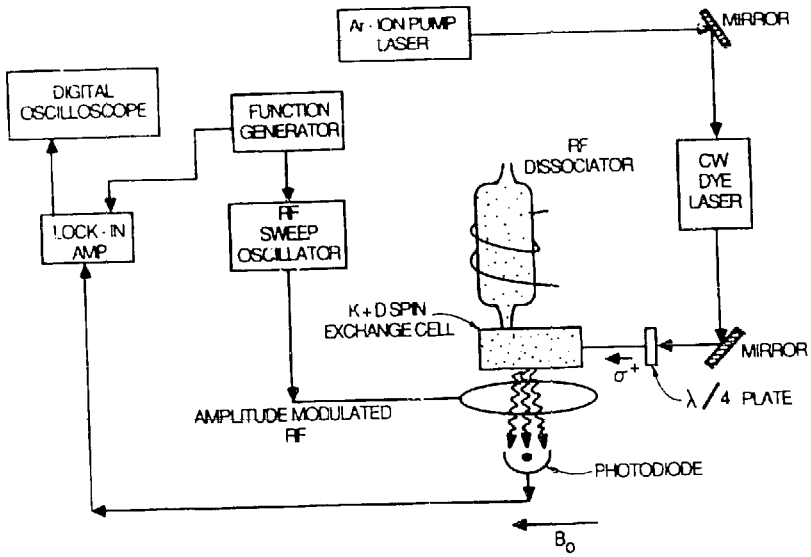

Fig. 1 Schematic diagram of the experimental set-up to observe polarization of K, H, or D in a flow system.

The best result we have obtained to date has been a polarization of 10% with a flux of 5.7×10^{16} H atoms/s. These results were obtained using a dri-film surface at ~ 300°C. We appear to be limited by the presence of K on the surface of the spin exchange cell at high alkali densities. We are presently investigating low K-density cells in order to minimize the surface contamination.

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