Consequences of Spin-Exchange Collisions for Polarized Hydrogen and Deuterium Targets

Recently Coulter *et al.* [1] demonstrated that spin-exchange collisions between deuterium atoms and optically pumped potassium atoms in a high magnetic field can produce 73% electron-spin-polarized D atoms at a flow rate of 2.1×10^{17} nuclei/s. Such a source of polarized D, used with a rf transition unit for transferring the electronic polarization to nuclear polarization, is of current interest for use as a polarized internal target for scattering experiments at storage rings. In Ref. [1] it is stated that only the D electron spin is polarized in the optical pumping cell, and that rf transitions can be used to obtain tensor polarizations approaching ±1. In this Comment we point out that under the conditions of Ref. [1] the D nuclei are directly polarized by spin-exchange collisions, and spin-exchange collisions will also affect the tensor polarization attainable in such a polarized target.

Nuclear polarization arises from spin-exchange collisions due to coupling of the electronic and nuclear spins by the hyperfine interaction. In a large magnetic field this coupling is reduced, but if sufficient numbers of collisions occur substantial nuclear polarizations can still be produced. In the optical pumping cell of the apparatus described in Ref. [1] the following estimates suggest that this is the case. In the optical pumping cell we estimate that a D atom makes on the average 40 spin-exchange collisions with polarized K atoms and $N=580$ spin-exchange collisions with other D atoms. Because of the incomplete decoupling of the D nuclear and electron spins by the 2.2 kG magnetic field, following each spin-exchange collision approximately $1/x^2=(\delta\nu_{\rm hfs}/g_s\mu_B B)^2=0.0028$ of the electron spin polarization is transferred to the nucleus. Despite this small coupling of the nuclear and electronic spins, the value $N/x^2=1.6$ implies a nuclear polarization approaching the electron spin polarization. Thus the D nuclei are substantially polarized by the spin-exchange optical pumping even at large magnetic fields.

D-D spin-exchange collisions may also be important in the exit tube. We estimate that on the average more than 10 spin-exchange collisions occur in the exit tube. Again, the magnetic field is important. The relevant number of collisions required to transfer electronic angular momentum to nuclear angular momentum is approximately $1+x^2$. Although both the D atom density (which drops from 1.7×10^{13} cm^{-3} to nearly zero across the tube) and the magnetic field (which drops from 2.2 kG to 100 G [2]) depend on position in the exit tube, making precise estimates difficult, the large number of collisions suggests that significant angular momentum transfer to the D nuclei by spin-exchange collisions may also be occurring in the exit tube. Both tensor and vector nuclear polarizations will be affected by these collisions. We note that the addition of a storage cell tube to the end of the apparatus will increase the number of collisions even more.

There are several consequences of these ideas for nuclear-polarized H and D targets. First, for experiments that require vector nuclear polarization, the direct polarization of the nuclei by spin exchange is advantageous since it eliminates the necessity for the rf transitions used in current atomic beam sources. For this application, even higher H fluxes then demonstrated in Ref. [1] should be possible. Second, the larger hyperfine splitting of H compared to D and consequent smaller values of x mean that polarized H targets should be polarized with fewer spin-exchange collisions (at a given field) than D. Third, careful design of tensor polarized D targets to eliminate spin-exchange collisions after any rf transitions have been made will be necessary to attain a controllable tensor polarization. Also, the modification of the populations of the various states by spin-exchange collisions upstream from the rf transition region will have to be taken into account. We note that in fields below a few hundred Gauss even a single spin-exchange collision will substantially modify the tensor polarization. In the limit of sufficient numbers of collisions, the system will attain a spin-temperature distribution [3]. In the spin-temperature limit the tensor polarization depends only on the total angular momentum of the atom and is always positive.

It is clear from these considerations that the transfer of angular momentum between the electronic and nuclear spins due to spin-exchange collisions will be important for high-density polarized H and D targets. Detailed calculations will be presented in a future publication.

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[1] E. Coulter, R. Holt, E. Kinney, R. Kowalczyk, D. Potterveld, L. Young, B. Zeidman, A. Zghiche, and D. Toporkov, Phys. Rev. Lett. **68**, 174 (1992).
[2] B. Zeidman *et al.* (private communication).
[3] L. W. Anderson, F. M. Pipkin, and J. C. Baird, Phys. Rev. **120**, 1279 (1960); W. Happer, Rev. Mod. Phys. **44**, 169 (1972).

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