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Progress in the polarization of HD ☆

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Abstract

The static polarization of HD samples has been achieved using "brute force", for HD samples purified by double distillation. Proton polarization in excess of 60% and deuteron vector polarization higher than 14% have been reached. It has been demonstrated that the ageing technique allows to get relaxation times at 1.5 K and 1 T larger than a week. It is advocated that the conventional dynamic polarization of HD should be feasible for the proton and the deuteron contained in the HD molecule. This would create the possibility of polarizing DT molecules, increasing their reactivity when used as fuel in HIIF processes.

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1. Introduction

For polarized HD targets, all nuclear species in the target are polarizable. With commercially available dilution refrigerators (10 mK) and superconducting magnets (15 T), the static polarization of H could reach 90% and the D vector polarization exceed 30%. H and D can be polarized independently and their relative orientation can be either parallel or antiparallel [1].

A view of the HYDILE target (HYdrogen Deuterium for Intersecting Laser Electron beams) can be found in Ref. [2]. This polarized HD target has been constructed under French leadership, within a French-Italian (IN2P3-INFN) collaboration, to perform polarized photoproduction experiments using the fully polarized high-energy backscattered photon beam of the GRAAL set-up at the European Synchrotron Radiation Facility (ESRF) in Grenoble (France) [3].

The present paper gives the last status of the HYDILE project based on the static polarization of HD samples. Given the very long relaxation times which can be achieved with purified and aged HD, it is argued that the Dynamic Nuclear

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Polarization (DNP) of suitable HD material should be investigated again. If fully successful, the DNP method would allow to produce "dream" polarized targets which could be polarized and used at high temperature and low field, typically 0.5 K and 1 T. In addition, the HD DNP technique could be readily applied to the polarization of DT molecules, with the goal to increase their reactivity when used as a fuel material in Heavy Ion Inertial Fusion (HIIF) [4].

2. Static polarization

Equipments for producing polarized HD targets are now operating at the IPN Orsay (France). A detailed description of this material has already been published [5]. This comprises essentially a Dilution Refrigerator (DR): 10 mK–13.5 T, in which HD targets are statically polarized; a Transfer Cryostat (TC): 4 K–0.35 T, allowing to remove the targets from the DR to put them into the variable temperature and a Storage Cryostat (SC): 1.5–20 K–2.5 T.

In the early polarization runs, the HD targets were made of commercially available HD gas with H_2 and D_2 concentrations around one percent. Small concentrations of ortho (o-H_2) and para (p-D_2) are necessary for the polarization process, however, the above values are at least 10 times too high, compared to ideal concentrations [1]. With such contaminations, relaxation times were still short, even after 40 days of ageing. Nevertheless, we succeeded in transferring a polarized sample from the DR to the SC, with a loss of polarization of 35% [5].

The polarization rate for protons was 60% and the vector polarization for deuterons was 14% before the transfer. With double distilled HD, as available now, much longer relaxation times have been achieved and the polarization losses during the transfers will be small. In the course of the ageing process, during which the polarized HD target remains in the DR at very low temperature (15 mK) and high field (13.5 T), the o-H_2 and p-D_2 impurities decay to their $l = 0$ orbital angular momentum ground states p-H_2 and o-D_2, with time constants of 6.25 days for H_2 and 18.25 days for D_2. The symmetry requirements for H_2 and D_2 wave functions force a simultaneous change of both spin and orbital quantum numbers, producing metastable excited states and long decay constants. The hetero-HD molecule has no symmetry requirements (one boson "D" and one fermion "H"), allowing all HD molecules to occupy their ground states right away at the low temperatures considered here.

Molecules in their $l = 0$ orbital angular momentum ground states, cannot mediate energy transfers between the "spin reservoir" and the lattice. Therefore, spin relaxation times can become very long, even at "high" temperature and low holding field. For HD targets, the spins are frozen, not by maintaining the target at low temperature as for conventional dynamically polarized targets, but by cutting the depolarization paths, going through o-H_2 and p-D_2 residual impurities. Fig. 1 shows the relaxation times T_1^H measured at Orsay as a function of the ageing.

It should be noted that, after 85 days of ageing, T_1^H is still increasing at a slow rate, showing that the system has not yet reached the physical limits of the relaxation times. The T_1^H evolution has been purposely measured at 1.9 K and 1 T, which are typical conditions of the SC. We see that after 60 days in the DR, T_1^H grows larger than 2 days, allowing the transport of the polarized HD from Orsay to Grenoble (10 hours). On the other hand, at 0.5 K and 1 T as in the IBC, T_1^H could reach 100 days! Therefore, the measured relaxation times can become long enough to allow all the phases of a typical nuclear physics experiment to be performed efficiently.

3. Dynamic polarization

A full production cycle for a polarized HD target using the "brute force" method, with the best double distilled HD (H_2 and D_2 concentrations $\approx 2 \times 10^{-4}$), takes at least 40 days. This is why a method to achieve DNP in HD seems highly desirable. Besides, for DNP, more convenient conditions of target production, i.e. lower fields and higher temperatures, can be expected to be sufficient. In 1973, J.C. Solem investigated the DNP in radiation-damaged solid HD, reaching