Status of Frozen-spin Polarized HD Targets for Spin Experiments

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Abstract. The first experiments have been carried out with polarized HD targets at the Laser-Electron-Gamma-Source (LEGS) facility. By holding targets at low temperature and high field (17 mK and 15 Tesla) in a Dilution Refrigerator (DF) for six weeks a frozen-spin state was reached, with equilibrium polarizations for protons and deuterons of 70% and 17%, respectively. Multiple measurements of the relaxation times and multiple transfers of the targets reduced these values so that experimental runs were carried out with polarizations of 30% and 6%, respectively. The relaxation times for protons and deuterons were observed to be 13 days and 36 days, respectively, in the beam line cryostat at 1.3 K and 0.7 Tesla magnetic field. For the future runs significantly higher D polarizations are possible by transfer of spin from the proton to the deuteron using an rf forbidden adiabatic fast passage. Higher polarizations and longer relaxation times are expected from ongoing development.

INTRODUCTION

Recently, experiments have started using circularly polarized photon beams with longitudinally polarized hydrogen and deuteron targets in Mainz [1], Bonn [2] and BNL [3][4]. Motivating these efforts have been tests of the Gerasimov-Drell-Hearn (GDH) sum rule first derived in 1966 [5] [6] and the forward nucleon spin-polarizability sum rule [7].

At LEGS, the first doubly polarized measurements were carried out in November 2001. The experiments used circularly and linearly polarized photon beams obtained by a laser induced backward scattering at the National Synchrotron Light Source at Brookhaven National Laboratory, using detectors for charged and neutral particles which cover almost the solid angle of four-π and a frozen-spin HD target. The solid HD target has a much smaller dilution factor than other solid target materials and background reactions with unpolarized nucleons are significantly reduced.
FROZEN-SPIN HD TARGET

The spins of two identical protons in an $H_2$ molecule at a low temperature are antiparallel in their lowest energy state (para); the para-$H_2$ can not be polarized. An ortho-$H_2$ molecule with a spin-parallel state for the two protons, is readily polarized at a high magnetic field and a low temperature. Three forth of all the $H_2$ molecules at room temperature are in the ortho state. At a low temperature, these decay into para-$H_2$ with a half life of about six days. An HD molecule consists of non-identical particles and there is no constraint as for the para-$H_2$.

A polarized ortho-$H_2$ transfers its polarization to HD due to a spin-spin coupling between an H in $H_2$ and an H in HD. This process happens on the order of hours. A small concentration of polarized ortho-$H_2$ (on order of $10^{-4}$) is used to polarize HD and most of the ortho-$H_2$ decays into the para state in two months. There are no phonons to couple an S-wave HD to its crystal lattice; thus once polarized, HD has an extremely long relaxation time. A frozen spin state can be achieved by simply keeping the HD at high field and low temperature.

HD gas is isotopically purified by distillation, doped with a small amount of ortho-$H_2$, and frozen into a mesh of 2000 pure aluminum wires whose diameter is 51 microns and which conducts away the heat from the ortho to para conversion of the $H_2$ impurity. The target holder is made of Kel-F which does not contain hydrogen. The target contains one mole (3 grams) of HD and has a length of 5 cm with respect to the photon beam direction and a diameter of 2 cm. A schematic drawing of the HD ice, its target holder and aluminum wires in the nose of the InBeam Cryostat (IBC) is shown in Figure 1.

In September 2001, high field/low temperature equilibrium polarizations of 70% for H and 17% for D were obtained after aging for six weeks. In Figure 2 thermal equilibrium polarizations for hydrogen and deuterium are shown as a function of a temperature under a magnetic field of 15 Tesla. The frozen-spin targets were transferred to an IBC using a Transfer Cryostat (TC) which has a temperature of about 2 Kelvin and a minimum magnetic field of 0.016 Tesla. Multiple measurements of the relaxation times and multiple transfers of the targets reduced these values so that experimental runs in November 2001 were carried out with polarizations of 30% and 6%, respectively. The relaxation times in the IBC for protons and deuterons were observed to be 13 days and 36 days, respectively.

RECENT PROGRESSES

In a magnetic field of 15 Tesla, vibrations transferred along pumping lines induce eddie currents which heat the copper support tube to which three HD target holders are thermally connected. This heat results in increasing the temperatures of the targets and limiting the polarizations. A vibration isolator using gimbal mounts [8] in the pumping line has been recently installed and tested successfully [9]. This improvement is expected to increase the thermal equilibrium polarization to 80% and 22% for H and D, respectively.

Significantly higher D polarizations are possible by transfer of spin from the proton
FIGURE 1. HD ice, its holder (Kel-F) and 2000 pure aluminum wires whose diameter is 51 microns to cool down the HD solid effectively.

to the deuteron using an rf forbidden adiabatic fast passage. In Figure 3, a transfer of proton polarization to deuterons by such a passage is shown on NMR signals. Coils for the passage have been installed in the DF. Our goal of the deuteron polarization is 50%.

A cross coil method has been used for the NMR system, leading to significant improvements [10].

FUTURE PLANS

Two new cryostats are under designing and fabrication. The present IBC was constructed by collaborators in Orsay, France. It operates as a $^4$He evaporation cryostat in which 1.3 Kelvin under a magnetic field of 0.65 Tesla are obtained for holding the HD target as a frozen-spin target in the beam line. This will be replaced by a new IBC using a
FIGURE 2. H and D thermal equilibrium polarization versus temperature under a magnetic field of 15 Tesla.

Forbidden Adiabatic Fast Passage

Efficiency of transfer = 67%

FIGURE 3. An example of the NMR signals for the rf forbidden adiabatic fast passage. The proton polarization before the passage (top) is transferred to deuteron (bottom). The second from the top shows an NMR signal for protons after the passage, while the second from the bottom shows one for deuterons before the passage. The NMR signal sizes are proportional to polarizations.
dilution refrigerator to achieve 0.2 Kelvin with a 1.0 Tesla field. The lower temperature and higher magnetic field are expected to increase the relaxation time for the hydrogen and deuterium at least a factor of 2. At some point, the production of free radicals by ionization from beam-generated $e^\pm$ pairs will become a limiting factor to the in-beam relaxation time, but this has yet to be determined.

The present TC, also fabricated by Orsay collaborators, keeps a target at about 2 Kelvin and has a minimum magnetic field of 0.016 Tesla. Relative polarization losses during the transfers from DF to IBC (lasting about 45 minutes) were 3% and 8% for protons and deuterons, respectively. To reduce these losses, a new TC has been designed by BNL, and will be fabricated and tested by Juelich in Germany. That will have a minimum magnetic field of 0.16 Tesla which is ten times higher than that of the present one.

Both cryostats are expected to be delivered to BNL in the middle of 2003.

**SUMMARY**

The first scattering experiments using a polarized HD target were performed at BNL in November 2001. Higher polarizations for the deuteron are expected for experiments in 2003 due to recent progress. Future improvements of the system will lead to longer relaxation times for proton and deuteron polarizations in beam and smaller polarization losses during target transfers.

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**REFERENCES**