Noble gas hyperpolarization for quantum memories with SEOP

Andrés Medina Herrera[1], Denis Uhland[2], Alexander Erl[3,4,1], Norman Vincenz Ewald[3,1], Ilja Gerhardt[2], Janik Wolters[3,4], Wolfgang Kilian[1] and Jens Voigt[1]

[1] Physikalisch-Technische Bundesanstalt, 8.22 Metrology of Ultra-Low Magnetic Fields, Berlin, Germany
[2] Leibniz University Hannover, Institute of Solid Stated Physics, Hannover, Germany
[3] German Aerospace Center (DLR), Institute of Optical Sensor Systems, Berlin, Germany
[4] Techinische Universität Berlin, Institute of Optical and Atomic Physics, Berlin, Germany

Nuclear spin-half systems, made of noble gases (such as ^{3}He or ^{129}Xe), show hour-long coherence times in magnetically shielded environments [1]. Through coupling to the electron spins of alkali vapour atoms, vapour-cell based electron-nuclear spin comagnetometers are commonly employed in precision measurement [2]. Recently, Firstenberg et al. proposed a quantum memory scheme that should substantially extend the storage time from the millisecond regime, achieved in alkali vapour [3,4] into the minute, or even hour regime [5], allowing for the application as a quantum token. This enhancement is realised via an enhanced alkali-noble gas spin coupling.

Here, we present the initial steps towards developing an experimental setup for hyperpolarizing noble gas using spin-exchange optical pumping (SEOP) ether on ^{129}Xe or ^{3}He. The experimental arrangement includes a glass cell containing a mixture of Rb and ^{129}Xe/^{3}He, placed in a table-top magnetic shield and heated to different temperatures to increase the vapor density. A dual-axis optical system has been implemented. A circularly polarized 795 nm (Rb-D_1 line) beam optically pumps the Rb spins, which gradually polarize the ^{129}Xe/^{3}He nuclear spins through SEOP. Perpendicular to the pump beam, a linearly polarized 780 nm (Rb-D_2 line) beam monitors the polarization of the Rb spins using Faraday rotation. A heating system applying forced hot air was compared to an AC current driven resistive heating oven.

The measured parameters include the build-up time of ^{129}Xe/^{3}He polarization, as well as the T_1 and T_2 relaxation times. We analyzed the potential factors affecting the efficiency of the polarization process, such as the influence of the magnetic field intensity B_z and the pump beam intensity, with the objective of determining the conditions for maximum sensitivity. Furthermore, we demonstrate the coherent control of the nuclear spins via driven Rabi nutation, highlighting the long coherence time.

[1] Gemmel, C et al.,Eur. Phys. J. D, **303**, 57 (2010).
[2] Terrano, WA and Romalis, MV, Quantum Sci. Technol., **014001**, 57 (2021).
[3] Katz, Or and Firstenberg, Ofer, Nat. Comm., **2074**, 9 (2010).
[4] Esguerra, Luisa et al., Phys. Rev. A, **042607**, 107 (2023).
[5] Katz, Or et al., Phys. Rev. A, **042606**, 105 (2022).