MEOP hyperpolarized ^{3}He for improving precision in magnetic flux density measurement

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Currently the methods to disseminate the unit Tesla, the standardized physical quantity of magnetic flux density, are based on NMR measurements on thermally polarized proton nuclear spins in water samples [1]. Due to the low SNR of the water sample at low fields (<2 mT) and a rather insensitive absorption technique used at fields above 10 mT, the relative measurement uncertainty is limited within a range of 10^{-4} to 10^{-6} up to now. Since hyperpolarized ^{3}He gas offers increased SNR (independently of field strength) and long precession times ($T_2^\star$) in ultra-low fields [2] as well as at high fields [3], it has the potential to reach a higher precision in magnetic field metrology, over a broader field range, as was shown in the high field measurements [3]. Using metastability exchange optical pumping (MEOP) to achieve hyperpolarization [4] promises fast buildup times and avoids the interaction of the polarized alkali atoms on the ^{3}He precession when applying the spin exchange optical pumping technique necessitating complicated pulse sequences for decoupling [5]. We will present some improvements on the MEOP setup to achieve high and stable polarization and measurements, which were performed inside a commercial table-top four-layer magnetic shield with integrated coils to generate a constant B_0 in the order of µT, as well as a perpendicular and resonant B_1 field to flip the ^{3}He magnetization initiating spin precession. By using a commercial Rb optical pumped magnetic gradiometer (2.3 cm baseline), we were able to measure the precession of the ^{3}He magnetization and deduce the Larmor frequency at different B_0 magnetic field strengths. This allowed measurements of polarization, buildup times as well as $T_2^\star$ relaxation times. Repeating measurements with variations in the flip angle allows to study the systematic effect of a residual ^{3}He longitudinal magnetization on the detected ^{3}He Larmor frequency. These first results aim to fully characterize measurement uncertainties which may be minimized within an improved setup or could be fully addressed in the uncertainty calculation. To validate the precision of our setup, we further plan to perform measurements within a large magnetically shielded room in combinations with superconducting quantum interference device (SQUID) detection of the ^{3}He magnetization precession, which provides a more stable field environment and allows ≈ 50 times higher SNR [2]. This is aimed to compare the influence of the sensor type (Rb optical pumped magnetic gradiometer vs. SQUID) on the B_0 field as seen by the ^{3}He nuclei.

[1] K. Weyand, IEEE Trans. Inst. Meas. (2001) 50, 470 .
[2] C. Gemmel et al., Eur. Phys. J. D (2010) 57, 303.
[3] M. Farooq et al., Phys. Rev. Lett. (2020) 124, 223001.
[4] T. R. Gentile et al., Rev. Mod. Phys. (2017) 89, 045004.

[5] M. E. Limes et al., Phys. Rev. Lett. (2018) 120, 033401.