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Self-compensating comagnetometer for exotic physics searches

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Self-compensating noble-gas–alkali-metal comagnetometers are highly sensitive to spin-dependent perturbations, making them useful tools for both inertial sensing and precision searches for physics beyond the Standard Model. To optimize these sensors for long-term measurements, required for such applications, we address two key challenges: robust calibration and long-term operational stability. We present a universal, frequency-resolved calibration method based solely on the comagnetometer's time-domain response to a step change in the magnetic field [1]. This straightforward experimental procedure ensures accurate interpretation of both magnetic and nonmagnetic signals under a wide range of conditions.

Long-term stability of noble gas polarization is essential for continuous operation in precision experiments. In practice, this polarization decays over time due to magnetic field gradients, which lead to dephasing and relaxation of the nuclear spins. To mitigate this, we implement a method for zeroing magnetic field gradients inside the shielded environment, significantly extending polarization lifetimes. Additionally, we utilize a locked-loop control system that continuously maintains the system at optimal operating conditions, such as the compensation point, enabling uninterrupted measurements over extended periods [2].
We will present our our implementation of the noble gas polarization control and calibration routine in the context of our novel search for axion-like particles [3].

[1] M. Padniuk, E. Klinger, G. Łukasiewicz, D. Gavilan-Martin, T. Liu et al., Universal determination of comagnetometer response to spin couplings, Phys. Rev. Research 6, 013339 (2024).

[2] E. Klinger, T. Liu, M. Padniuk, M. Engler, T. Kornack et al., Optimization of nuclear polarization in an alkali-noble gas comagnetometer, Phys. Rev. Applied 19, 044092 (2023).

[3] D. Gavilan-Martin, G. Lukasiewicz, M. Padniuk, E. Klinger, M. Smolis, et al., Searching for dark matter with a 1000 km baseline interferometer, arXiv:2408.02668 (2024).

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