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Characterization of Mercury Vapor Cells for Nuclear Spin-Based OPMs Operating at High Atomic Densities

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Nuclear spin-based OPMs offer a path toward advancing sensitive magnetometry by leveraging the long coherence times of nuclear spin ensembles. Mercury (Hg), particularly its odd isotopes, is a promising candidate due to its accessible 254 nm $^1S_0 \to {}^3P_1$ optical transition and high vapor pressure—over 10^3 times that of cesium at room temperature—enabling large optical depths and nuclear spin optical pumping and readout. These properties can compensate for the inherently weaker nuclear magnetic moment, making Hg-based OPMs competitive with electron-spin-based devices. However, prior research [1,2,3] has focused on fundamental physics using cm-scale cells and sub-vapor-pressure densities at room temperature. The regimes of heated Hg vapor cells to reach high atomic densities and sub-mm^3 volumes, critical for sensitive magnetometry and microscopy applications, remain largely unexplored. This high density regime is also promising for quantum-enhanced protocols, where preparing spin-squeezed states via quantum non-demolition (QND) measurements relies on achieving high optical depths.

This work aims to identify favorable combinations of cell parameters that support long spin coherence times at high atomic densities by characterizing a diverse set of natural Hg vapor cells, varying in carbon monoxide (CO) buffer gas pressure, anti-relaxation coatings (bare glass, paraffin, and OTS), and mercury source (HgO vs. metallic Hg), using a 254 nm laser system. The outcomes will guide future designs of compact, high-sensitivity OPMs based on Hg vapor.

[1] M. D. Swallows, et al., Phys. Rev. A. **87**, 012102 (2013)
[2] nEDM Collaboration. Eur. Phys. J. C., (2021), 81:512
[3] S. K. Lamoreaux, https://arxiv.org/abs/2504.09040

Author: KIEHL, Christopher (ICFO - Institute of Photonic sciences)

Co-authors: MEDHAT, Hana (Institute of Photonic Sciences (ICFO)); MITCHELL, Morgan (ICFO - Institut de Ciències Fotóniques, 08860 Castelldefels (Barcelona), Spain)

Presenter: KIEHL, Christopher (ICFO - Institute of Photonic sciences)

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