Utilizing the Center-of-Mass for Sensing Magnetic Fields and Gravity in a Cold-Atom Cavity QED System with Magnetic Trapping

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We investigate a cold ensemble of magnetically trapped ^{87}Rb atoms, that can be magnetically transported into a high-finesse optical cavity. Within the cavity, the atoms are either kept in the magnetic trap, or transferred into a cavity-sustained optical dipole trap [1]. The cloud can be diagnosed by the scattering of a transverse laser into the cavity, where the resulting cavity field is monitored through one of the mirrors by single-photon detection after separating vertically and horizontally polarized photons.

With this system, we first exhibit the 'cold atom buoy' technique. In the magnetic trap we take absorption images of the ensemble, and compare the center-of-mass positions under reversed magnetic quadrupole polarities that reverses the translation caused by external fields. This allows for determining the true geometrical center of the quadrupole, and sensing external homogeneous bias fields at the position of the atoms in an intermediary regime above the range of optically pumped magnetometry.

Further, after transporting the atoms into the cavity, and by analysing the polarization-resolved cavity output, we can distinguish between Rayleigh and Raman scattering from the atoms. Since the latter scattering type corresponds to redistribution on magnetic sublevels, it is sensitive to magnetic fields. As the magnetic trap is pulled through the cavity axis, this allows for using the cavity as a tomograph to separately map out the density distribution of the atomic cloud (Rayleigh scattering) versus the trapping magnetic field (Raman scattering), the two differing due to gravity. Hence the gravitational sag of a magnetically trapped cold ensemble can be characterized.

The experiment is controlled using the Wigner Time Python package [3], a data-oriented tool for defining timelines of real-time control for cold-atom experiments, that defines and manipulates experimental timelines as pandas DataFrames with a functional-type API. This approach enables transparent and flexible software control, with seamless integration with the broader scientific Python ecosystem.

References

[1] D Varga, B Gábor, B Sárközi, *et al.*, Phys. Lett. A **505**, 129444 (2024)

[2] B Gábor, K V Adwaith, D Varga, *et al.*, arXiv:2408.17079 (2024)

[3] https://github.com/WignerQuantumOptics/Wigner_Time