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Quantum metrology for symmetry violation searches in molecular ion systems

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Precision measurements of time-reversal (T) symmetry violation in molecular systems provide stringent tests of new physics beyond the Standard Model. Recent measurements of the electron's electric dipole moment (eEDM) in both neutral molecules [1] and molecular ions [2] have excluded a broad parameter space of T-violating leptonic physics at energy scales up to ˜10 TeV. To improve the measurements further, it would be advantageous to trap molecules in stationary traps and apply quantum-enhanced metrology methods. However, for molecular ion systems, contemporary eEDM searches are conducted in non-stationary rotating traps, since an external electric field is needed to polarize the molecules.

I will present our recent proposal [3] of measuring the eEDM using entangled molecular ions without an external electric field. We propose to polarize the molecules by preparing a superposition of opposite parity states, where the orientation of the molecule is oscillating. We show that in a system of two (or more) oscillating molecules, the eEDM can be observed as a coupling between two entangled spin states within a decoherence-free subspace. Furthermore, the eEDM sensitivity scales linearly with the entangled molecule number, thereby offering Heisenberg-limited sensitivity beyond the standard quantum limit, while the susceptibility to electromagnetic fields remains mitigated.

Importantly, our method does not require an electric field to polarize the molecular ions. As a result, it is compatible with quasi-stationary ion traps, such as the linear Paul trap, in which a powerful toolbox of precision spectroscopy and quantum metrology has been developed.

[1] V. Andreev et al., Improved limit on the electric dipole moment of the electron, Nature 562, 355 (2018).

[2] T. S. Roussy et al., An improved bound on the electron's electric dipole moment, Science 381, 44 (2023)

[3] CZ et al., Quantum-Enhanced Metrology for Molecular Symmetry Violation using Decoherence-Free Subspaces, arXiv:2307.05858 (2023)

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