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Precise Spectroscopy of the Fundamental Vibrational Band in a Trapped Single Molecular Nitrogen Ion

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Precision spectroscopy of dipole-forbidden rotational and vibrational transitions in molecular ions presents a promising avenue for investigating fundamental physical theories, detecting variations in fundamental constants, and establishing new frequency standards. Until recently, achieving the necessary precision has been hindered by the lack of control over molecular ions at the quantum level.
Here, we introduce novel methodologies enabling the preparation of a single molecular ion, specifically N_2^+, in its rovibrational ground state and achieving high-fidelity quantum state detection. Leveraging techniques such as Doppler, Sideband, and EIT laser cooling, coupled with quantum-logic protocols utilizing co-trapped ions, we achieve quantum non-demolition state detection with fidelities exceeding 99%. Our focus now extends to the detection of quadrupole transitions within the fundamental vibrational band S(0). By referencing our spectroscopic measurements to the Swiss primary frequency standard at METAS, we ensure absolute frequency stability, paving the way for precision measurements with an absolute precision on the order of 10^{-15}.
Additionally, these advancements not only push the boundaries of molecular ion spectroscopy but also hold promise for applications in molecular quantum technologies, including the implementation of molecular qubits, mid-IR frequency standards, and high-resolution studies of state-to-state dynamics in chemical reactions.

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