Quantum logic and precision measurements with atomic and molecular ions

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The tools of trapped-ion quantum logic can be used to enable and enhance precision measurements with applications in the search for physics beyond the standard model. In this talk, I will present two experiments at this fertile intersection of fields. I will begin with a brief review of optical atomic clocks based on Al^+, which use quantum logic with a co-trapped second ion species for preparation and readout of the Al^+ state [1]. Recent progress, including an improved ion trap design and sympathetic laser cooling to the 3D ground state, has enabled total fractional systematic uncertainty below 10^{-18} [2]. We have performed frequency ratio measurements between Al^+ [2], Sr [3], and Yb [4] clocks with uncertainty below 10^{-17}, which can be used to place constraints on models of ultralight dark matter [5]. Next, I will describe an experiment in which quantum-logic readout is used to prepare pure rotational and hyperfine states of a single CaH^+ ion in a probabilistic but heralded fashion [6]. By directly driving coherent Raman transitions with a frequency comb [7,8], we characterize the THz frequencies of rotational transitions with sub-100-Hz resolution and generate entanglement between Ca^+ electronic states and CaH^+ rotational states. Our methods can be extended to study rotational and vibrational transitions of a large class of diatomic and polyatomic molecular ions that are useful in the search for new physics [9].

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