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Optimized Setup for Quantum Logic of Molecular Ions

Molecular ions have a rich level structure and therefore are useful for applications ranging from precision measurements to quantum information processing. Besides the motional degrees of freedom, they exhibit also vibrational and rotational degrees of freedom, rendering direct laser cooling a challenge. We demonstrate sympathetic motional ground state cooling of a $^{24}\mathrm{MgH}^+$ molecular ion through a co-trapped $^{25}\mathrm{Mg}^+$ ion in this chamber. In this setup, magnesium ions are loaded into the trap via isotope-selective photo-ionization of an atomic beam from a resistively heated effusive source. MgH^+ molecules are created by leaking hydrogen gas into the vacuum system while simultaneously exciting the magnesium ion with a laser to trigger photo-induced chemical reaction between the magnesium ion and the hydrogen molecule. The increased hydrogen background gas pressure of on the order of 10^{-8} mbar degrades the vacuum quality and induces collisions between the ions and the residual gas, mixing rotational states.

This situation can be improved in a newly designed vacuum system by using molecular beams for the loading process. A design of a new vacuum system will be presented which will improve loading and allow trapping of other molecular ion species with applications for tests of fundamental physics. Besides the experimental environment, the control of the various states of the molecular ions is necessary to perform spectroscopy. Our MgH^+ molecular ion is in the vibrational ground state at room temperature and can be laser-cooled sympathetically. A remaining task is the control of rotational states. This can be achieved by coupling these states via a frequency comb to coherently transfer the population from higher to lower rotational states. A non-destructive projective measurement of the target rotational state allows efficient population pumping. Once the rotational ground state is achieved ($J = 0$), the molecular ion can only move to the $J = 1$ state. When this transfer is detecting a pulse from a THz source can be applied to bring it back to the ground state. By combining the newly designed vacuum chamber with the radiation sources mentioned here, quantum logic spectroscopy of molecular ions will become practicable.

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