Rotational cooling of large trapped molecular ions

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Polyatomic molecules are a promising new platform for fundamental physics and quantum information processing due to their rich internal structure. In particular, their rotational degrees of freedom span a large, well-isolated Hilbert space with strong anharmonicities, enabling precise control. Utilizing these features requires trapping and rotational cooling of molecules. We consider polar molecular ions which are co-trapped with atomic ions in a linear Paul trap. Dipole interaction couples molecular rotation to the collective vibration of the particles in the trap [1, 2]. We demonstrate that the complex rotational spectrum of asymmetric top molecules enables strong dipolar coupling that can be utilized for sympathetic sideband cooling of the rotational degrees of freedom. Furthermore, by combining sideband cooling with coherent microwave control [3], we show that it is possible to tailor the rotational state distribution—either depleting arbitrary subspaces or cooling the entire manifold into a single rotational state.

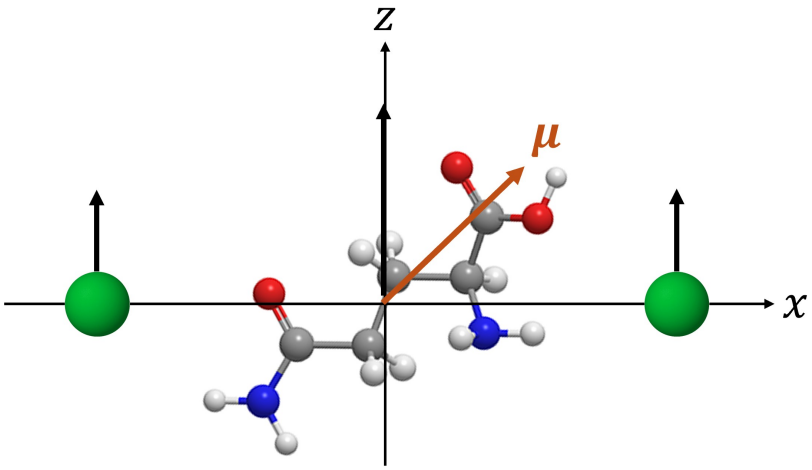

Figure 1: Protonated glutamine molecule co-trapped with two Yb^+ ions in a linear Paul trap. The black arrows indicate the collective vibration of the particles in the trap. The molecular dipole (orange arrow) coupes the rotational degrees of freedom of the molecule to the normal modes of the trap, making the rotational subspace amenable to sympathetic sideband cooling.

References

[1] W. C. Campbell, E. R. Hudson, *Phys. Rev. Lett.* **125**, 120501 (2020).

[2] M. Leibscher, F. Schmidt-Kaler, Ch. P. Koch, *arXiv:2504.00590* (2025).

[3] M. Leibscher, E. Pozzoli, C. Perez, M. Schnell, M. Sigalotti, U. Boscain and Ch . P. Koch, *Commun. Phys.* **5**, 110 (2022).