Quantum logic spectroscopy and sensing with trapped ions

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The exquisite control achieved over internal and external motional degrees of freedom in trapped and laser-cooled ions makes them ideal candidates for optical clocks and other precision measurements, such as electric and magnetic field sensors. I will provide an introduction into quantum logic techniques that enable this control and demonstrate several applications. In the first application, we use motional state engineering to measure forces from oscillating electric fields and the oscillation frequency of the ion in the trap with a sensitivity beyond the classical limit. Specifically, motional Fock states allow improved measurements of displacement and phase evolution using the same quantum mechanical resource [1].

In optical clocks, external electric and magnetic fields shift the resonance frequency and need to be carefully evaluated. In particular, when increasing the number of trapped ions in an optical clock to improve the signal-to-noise ratio, additional shifts arising from position-dependent oscillating electric fields and field gradients, lead to inhomogeneous broadening of the clock transition to several tens of Hertz. We employ dynamical decoupling techniques to suppress magnetic field shifts by six orders of magnitude with the potential to eliminate inhomogeneous broadening in large (tens to hundreds of ions) Coulomb crystals of Ca^+ ions to the Hertz level [2]. This may allow for a multi-ion frequency reference with low statistical uncertainty.

In the last example, a so-called logic ion is co-trapped with a spectroscopy ion to provide sympathetic cooling, state preparation and state readout using quantum logic operations. We use this quantum logic spectroscopy technique to perform the first high precision spectroscopy on a highly charged ion (HCI), specifically $^{40}Ar^{13+}$. Owing to their special electronic properties, HCI are sensitive probes for QED and dark matter [3]. At the same time they are much less sensitive to external electric fields, suggesting them as candidates for high-accuracy optical clocks to test fundamental physics [4].

References

[1] F. Wolf, C. Shi, J. C. Heip, M. Gessner, L. Pezzè, A. Smerzi, M. Schulte, K. Hammerer, and P. O. Schmidt, ArXiv:1807.01875 (2018).
[2] N. Aharon, N. Spethmann, I. D. Leroux, P. O. Schmidt, and A. Retzker, ArXiv:1811.06732 (2018).
[3] M. S. Safronova, D. Budker, D. DeMille, D. F. J. Kimball, A. Derevianko, and C. W. Clark, Rev. Mod. Phys. **90**, 025008 (2018).
[4] M. G. Kozlov, M. S. Safronova, J. R. Crespo López-Urrutia, and P. O. Schmidt, Rev. Mod. Phys. **90**, 045005 (2018).