Contribution ID: **37** Type: **Talk**

Towards quantum control and spectroscopy of single hydrogen molecular ions

Tuesday 4 July 2023 18:20 (25 minutes)

The complexity and variety of molecules offer promising applications in metrology and quantum information that go beyond what is possible with atomic systems. We aim to study light molecular ions that are amongst the most fundamental and simplest molecules. Their internal structure can be calculated, making them prime candidates for the determination of fundamental constants as well as for theory benchmarks.
Spectroscopy of single ions is expected to reduce systematic uncertainties and improve signal strength. However, this requires quantum control over the spectroscopy ion, which can be achieved by co-trapping it with a well-controlled logic ion. Using the technique of quantum logic spectroscopy, it has been shown that even hard-to-control ion species can be prepared in a pure quantum state and measured non-destructively with high precision.
I will present our progress towards full quantum control of the hydrogen molecular ion H_2^+ and its reaction product H_3^+, each co-trapped with a beryllium ion in a linear Paul trap. We have demonstrated H_2^+ trapping times of up to 11^{+6}_{-3} hours, enabled by cryogenic pumping of background H_2 that suppresses chemical reactions converting H_2^+ to H_3^+. We have achieved ground-state cooling of one of the motional modes of both H_2^+ and H_3^+, which is one of the first steps in many implementations of quantum logic spectroscopy. In addition, our cryogenic apparatus should allow for the use of buffer gas to cool the rovibration of molecular ions to their ground state.

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Session Classification: Molecules