Quantum-logic precision spectroscopy and control of trapped molecules

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Trapped ions are among the best-controlled quantum systems. However, for molecules, a similar degree of control currently lacks due to their complex energy-level structure. Quantum-logic protocols in which atomic ions serve as probes for molecular ions are promising for achieving this level of control. Here, I will describe our experimental results in achieving >99% fidelity in the quantum-nondemolition state detection of the nitrogen ion's electronic, vibration, and rotation ground state [1], thus making a crucial step towards the coherent manipulation of molecular quantum states. We further exploited our quantum-logic protocol for hyperfine and Zeeman resolved state identification and preparation in a complex region of the molecular spectrum, mimicking the situation encountered with polyatomic molecules [2].

The quantum control of rotation and vibration of molecules will significantly enhance the precision of molecular spectroscopy. It will open up opportunities for creating new time standards in the THz domain [3], searching new physics such as possible time variation in the proton-to-electron mass ratio, and encoding quantum information in molecular qubits at telecom frequencies for quantum-communication applications.

[1] Sinhal, ZM, Najafian, Hegi, Willitsch, Science 367, 1213 (2020).
[2] Najafian, ZM, Sinhal, Willitsch, Nat. Commun. 11, 4470 (2020).
[3] Najafian, ZM, Willitsch, Phys. Chem. 22, 23083 (2020).
[4] ZM, Hegi, Najafian, Sinhal, Willitsch, Faraday Discuss. 217, 561 (2019).

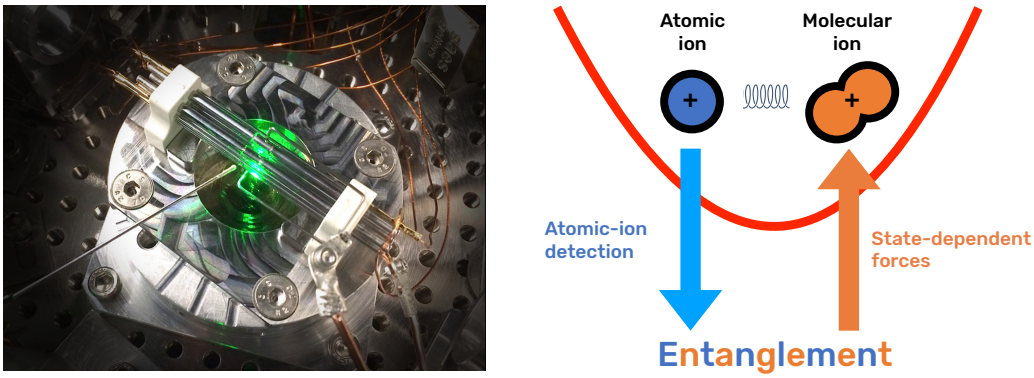

Figure: Left) Radio-frequency ion trap used for quantum-logic state detection and preparation of rovibrational molecular states in nitrogen molecular ion [4].
Right) Quantum-logic protocol. The strong coupling between trapped atomic and molecular ions is used for non-destructive and quantum non-demolition state detection of the molecular-ion state.