ÉCOLE DE PHYSIQUE des HOUCHES

UNIVERSITE JOSEPH FOURIER SCIENCES TECHNOLOGIE MEDECINE

Contribution ID: **12** Type: **not specified**

Quantum logic spectroscopy of molecular ions

Compared to atoms, molecules offer a rich level structure, permanent dipole moment, large internal electric field and additional symmetries. Therefore, molecular quantum systems are well suited for many applications such as quantum computing, high precision spectroscopy, test of fundamental physics, as well as quantum chemistry and astrochemistry.

However, in general direct laser cooling and fluorescence state detection is not applicable, due to the lack of closed optical transitions. Thus, advanced quantum logic spectroscopy techniques, especially for states with short lifetimes lend themselves a powerful readout tool for molecular ions. For the implementation of quantum logic schemes for polar molecules, quantum state preparation poses another challenge, since the rotational states are strongly coupled by blackbody radiation, which makes rotational cooling necessary. Recently, different ro-vibrational cooling techniques ranging from optical pumping to sympathetic cooling have been reported. Although several techniques for rotational cooling were demonstrated, coherent manipulation of single molecular ions for quantum computing or spectroscopy has still remained unfeasible, due to the destructive nature of common state detection techniques e.g. state-selective dissociation (REMPD) or chemical reactions. Here, we present a non-destructive rotational state detection scheme and demonstrate its capability for spectroscopy by implementing an advanced quantum logic spectroscopy scheme combining methods of spectroscopy and quantum computing.

For this purpose, we prepare a translationally cold molecular ion ($^{24}MgH^+$) in a specific ro-vibrational state by employing a variation of the quantum logic technique in which a laser-cooled atomic ion ($^{25}Mg^+$) is simultaneously trapped with a single molecular ion. The cooling of the external degrees of freedom of the molecular ion is achieved via sympathetic cooling by the sideband-cooled atomic ion, while the preparation of its internal state is achieved via a quantum-non-demolition measurement (QNDM), where the internal state information of the molecule is mapped onto the shared states of motion. The motional state can be read out by applying sideband pulses on the atomic ion and subsequent detection of its internal state.

By analyzing the signal obtained from the QNDM we can extract spectroscopic information about the $X^1\Sigma^+ \rightarrow A^1\Sigma^+$ transition.

Summary

We present a non-destructive rotational state detection scheme and demonstrate its capability for spectroscopy of a single molecular ion by implementing an advanced quantum logic spectroscopy scheme combining methods of spectroscopy and quantum computing.

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