DAMOP16-2016-020050

Abstract for an Invited Paper
for the DAMOP16 Meeting of
the American Physical Society

Quantum logic with molecular ions

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Precision spectroscopy is a driving force for the development of our physical understanding. However, only few atomic and molecular systems of interest have been accessible for precision spectroscopy in the past, since they miss a suitable transition for laser cooling and internal state detection. This restriction can be overcome in trapped ions through quantum logic spectroscopy [1]. Coherent laser manipulation originally developed in the context of quantum information processing with trapped ions allow the combination of the special spectroscopic properties of one ion species (spectroscopy ion) with the excellent control over another species (logic or cooling ion). I will show how the internal state of a molecular ion can be detected non-destructively on a co-trapped cooling ion by implementing a quantum logic algorithm involving only coherent laser manipulation on the molecular ion [2]. An optical dipole force tuned to near one of the molecule's resonances interacts with the molecular ion only if it is in a specific state. The resulting change in the motional state of a two-ion crystal formed by the molecular and atomic ion can be efficiently detected through the latter. More specifically, we detect if the MgH^+ molecule is in the rotational state J=1 in the vibrational and electronic ground state. We observe quantum jumps into and out of this state that are driven by ambient black-body radiation. We use the detuning dependence of the dipole force to perform spectroscopy on an electronic transition. This represents a first step towards extending the exquisite control achieved over selected atomic species to much more complex molecular ions. [1] P. O. Schmidt, T. Rosenband, C. Langer, W. M. Itano, J. C. Bergquist, and D. J. Wineland, *Spectroscopy Using Quantum Logic*, Science **309**, 749 (2005). [2] F. Wolf, Y. Wan, J. C. Heip, F. Gebert, C. Shi, and P. O. Schmidt, *Non-destructive state detection for quantum logic spectroscopy of molecular ions*, Nature **530**, 457 (2016).