

Ultracold molecules strongly coupled to a nanophotonic crystal: an universal platform for ultracold chemistry experiments

J. Pérez-Ríos^{*1}, M. Kim^{*2} and C.-L. Hung^{*3}.

^{*} Department of Physics and Astronomy, Purdue University, West Lafayette IN 47907, USA

Synopsis We develop a novel platform for the study of ultracold chemical reactions and quantum information protocols based on the strong coupling between ultracold molecules and a nanophotonic device.

The possibility of controlling and manipulating atoms as well as internal degrees of freedom of molecules nowadays is the main driving force in the field of atomic, molecular and optical (AMO) physics as well as in chemical physics. In particular, such degree of control is the first step towards quantum memories, quantum logic spectroscopy, and state selective chemistry, among other applications. However, despite the promising applications of photonics devices, the study of ultracold molecules in the presence of photonics devices has remained largely unexplored. Indeed, the presence of internal degrees of freedom in ultracold quantum emitters coupled to photonic modes may lead to unprecedented coherent control of chemical reactions, robust non-destructive measurements techniques, and state-selective strong coupling mechanisms

We propose a novel method for deterministic production and manipulation of ultracold molecules (temperature $< 1\text{mK}$) in their rovibrational ground state. In particular, we seek to enhance PA conversion efficiency to ground state molecules by making use of the paradigmatic waveguide and cavity quantum electrodynamics (QED) [?]. In the proposed experiment, a nanophotonic structure will be devised to trap magneto-optically pre-cooled atoms, efficiently guide the photoassociation light to excite trapped atoms into electronically excited bound states, and selectively enhance the subsequent radiative decay channel into a single molecular quantum state leading to $> 99\%$ conversion efficiency and $> 1\text{MHz}$ production rate of ultracold molecules in a given rovibrational state. Most importantly, exactly the same photon following spontaneous emission will be collected by the nanophotonic structure, and can be detected

and analyzed to inquire the information about the final molecular state. Taking the advantage of strong light-molecule coupling, the nanostructure can also be used to guide light and perform subsequent quantum control, such as coherently driving transition between rovibrational states or inducing controlled ultracold chemical processes.

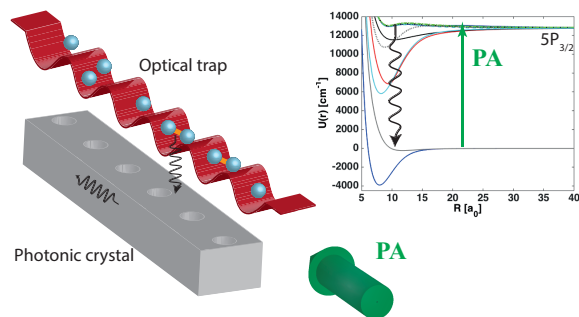


Figure 1. Photoassociation of Rb_2 in the presence of a photonic crystal. The photoassociation (PA) laser is blue detuned from the $5P_{3/2}$ atomic line of Rb, leading to the formation of molecules in an excited electronic state, and decaying in a time $\sim 10\text{ns}$ to a broad distribution of vibrational states associated with the $a^3\Sigma$ state. However, the presence of the photonic crystal highly suppress all these decay modes except one, corresponding to the decay to the ground vibrational state, which is on resonance with the guiding mode of the photonic crystal.

References

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¹E-mail: jperezri@purdue.edu

²E-mail: kim2257@purdue.edu

³E-mail: clhung@purdue.edu