Quantum chemistry with ultracold molecules

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Laser cooling has enabled the production of molecules at a phase-space density that is sufficiently large for quantum degeneracy effects to dominate. Extremely low temperatures have also allowed the confinement of these molecules in electric, magnetic, and optical traps, where they are isolated from their environment and can be carefully studied. A diverse list of promising applications for ultracold molecules exists. This includes performing precision spectroscopy to test the Standard Model of particle physics, creating new types of sensors, advancing quantum information science, simulation of complex exotic materials and, excitingly, the promise of quantum control of chemical reactions as each molecule can be prepared in a unique ro-vibrational quantum state.

Crucially, the de-Broglie wavelength of ultra-cold atoms and molecules is much larger than the range of intermolecular forces and thus collisions and reactivity among these particles is governed by quantum statistics. Here, we have experimentally and theoretically studied [1,2] resonant scattering of ultracold bosonic and fermionic atoms and molecules in an external magnetic field. We located a number of magnetic Feshbach resonances, where three-body recombination processes are resonantly enhanced. A comparison of experimental and theoretical line profiles of the three-body recombination process at various temperatures has shown that recombination is controlled by specific partial wave scattering of the three-atom entrance channel. Entrance channels with zero and nonzero tri-atomic total orbital angular momentum lead to line shapes with a unique temperature behavior. Our analysis was facilitated by the experimental ability to observe Feshbach resonances at nK and μK temperatures.

[1] T. Maier, H. Kadau, M. Schmitt, M. Wenzel, I. Ferrier-Barbut, T. Pfau, A. Frisch, S. Baier, K. Aikawa, L. Chomaz, M. J. Mark, F. Ferlaino, C. Makrides, E. Tiesinga, A. Petrov, and S. Kotochigova, Phys. Rev. X **5**, 041029 (2015).

[2] A. Green, H. Li, M. Li, E. Tiesinga, S. Kotochigova, and S. Gupta, submitted to PRX (2019).