Collisions between cold molecules in a superconducting magnetic trap

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Synopsis We decelerate and trap molecular oxygen using time-dependent magnetic fields and superconducting magnets. The density-dependent, non-exponential decay in particle number provides a clear proof of molecule-molecule collisions within the trapped ensemble. The spatial distribution of molecules in the trap is found to change over time, allowing to set limits on the ratio between the elastic and inelastic collision cross sections. Our experimental scheme opens up new possibilities for studying quantum effects in chemistry as well as for evaporative cooling of molecules.

Cold dense ensembles of molecules allow studying a large variety of topics, from quantum phenomena in chemical reactions to the possible achievement of quantum degeneracy with complex species.

Following the success of atom laser cooling, Feshbach molecules are now routinely created by magneto-association of cold atomic species. Directly cooling and trapping neutral molecules has turned out to be much more complicated, mainly because of the large number of vibrational and rotational states that makes laser cooling a challenge. Deceleration and subsequent trapping of dense molecular ensembles has emerged as a promising alternative.

We present here first measurements of collisions between magnetically decelerated and trapped molecules[1].

A cloud of O_2 molecules is created by a pulsed supersonic expansion and decelerated in a moving magnetic trap decelerator[2]. At the end of the deceleration, a superconducting magnetic trap, made of high-T_c superconducting tape, is switched on, allowing constant or time-dependent traps to be realized. The detection is carried out by a 2+1 REMPI (resonance enhanced multi-photon ionization) scheme, yielding the particle density integrated over the laser propagation direction.

We observe a clear non-exponential decay that depends on the O_2 density (Figure 1).

We provide an independent proof of molecular collisions by co-loading lithium atoms together with the molecular oxygen. We observe that the lifetime of lithium is reduced from background collision limited lifetime of 14 s to 1.9 s due to the collisions with oxygen.

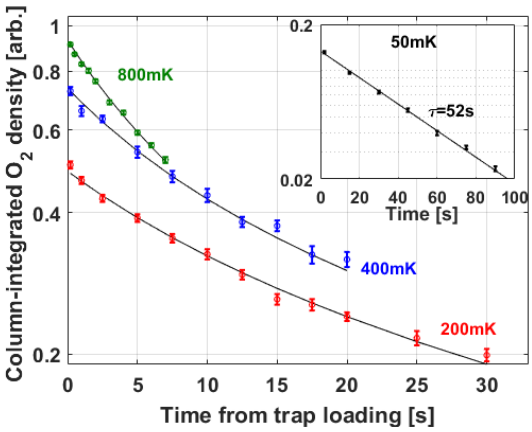

Figure 1. Time evolution of the column-integrated O_2 density for different trap depths, given in E_{max}/k_B. While the decay in the shallow trap (50 mK) is exponential due to pure background collisions, higher densities show a non-exponential slope due to collisions between trapped molecules.

Our detection scheme allows probing the density at different locations in the trap. We observe a faster decay at the edges of the trap, indicating a redistribution due to elastic collisions. With the help of a classical simulation of collision dynamics, we are able to estimate the ratio of elastic to inelastic cross sections. Although for $^{16}O_2$, this ratio is not sufficient to apply direct evaporative cooling, the versatility of our method enables us to study now if different oxygen isotopes or other paramagnetic species have more favorable collisional properties.

References

[1] Segev Y, Pitzer M, Karpov M *et al* 2019 arxiv 1902.04549

[2] Akerman N *et al* 2017 *Phys. Rev. Lett.* **119** 073204

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