On the Sympathetic Cooling of Atomic and Molecular Ions with Ultracold Atoms

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ECTI 2010

Abstract

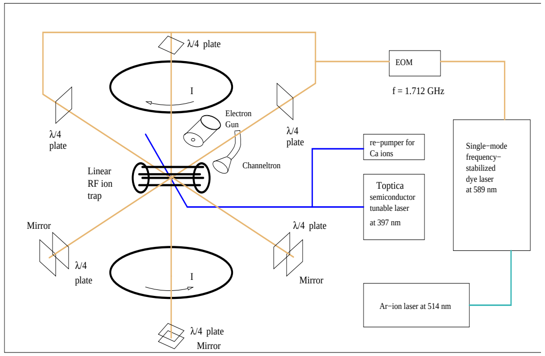
Ion collisions with ultracold neutral atoms are dominated by universal types of long-range polarization forces between charged particles and neutrals. For example, we have calculated the elastic scattering cross section in the mK range for Ca+ ions on Na atoms to be ~10^6 atomic units [1]. *These collisions have potential applications, for example, to ion-molecule reactions in the interstellar medium, to decoherence effects in trapped-ion quantum computing and quantum information experiments, as well as precision spectroscopy of molecular ions.* A hybrid cold ion-neutral trap has been built. Ultracold Na atoms are trapped in a vapor cell magneto-optic trap (MOT) and will be overlapped spatially with a small cloud of $^{40}Ca^+$ or $^{23}Na^+$ ions trapped in a co-located linear Paul radiofrequency trap, which we have constructed. We have indications that both traps can operate simultaneously without interference. We have successfully observed Na MOTs on two transitions (3s F=2->3p F'=3 and F=2->F'=2), we have improved the optics to ensure reliable operation, and are developing the Paul trap system and ion diagnostics. We hope to confirm theoretical predictions [1] that trapped atomic and molecular ions can be cooled very efficiently by collisions with the ultracold atoms in a high vacuum environment. The method is very general and can be used in cases where direct laser translational cooling of molecular ions is impractical. Once cooled, precision Doppler free spectroscopy and studies of reactions of molecular ions and atomic clock ions with neutrals become possible. Potential measurements of internal state *molecular-ion cooling* due to collisions with ultracold atoms are also of great experimental and theoretical interest. Other international theoretical and experimental groups are beginning to initiate research in this area, including a breakthrough experiment at Cambridge University [2] in which a single Yb+ ion was observed optically in its effect on de-trapping Rb atoms from a BEC. This general ion-cold neutral research area, which we were among the first to propose [3] (with theoretical help from Prof. R. Côté [4]), is proving to be of broad interest. We present a progress report on our current work.

[1] O Makarov, R Côté, H Michels and W Smith, Phys. Rev. A 67, 042705 (2003).
[2] C Zipkes, S Palzer, C Sias and M Koehl, Nature 464, 388 (2010); invited talk at ECTI 2010.
[3] W Smith, E Babenko, R Côté and H Michels, in *Coherence and Quantum Optics, VIII*, N Bigelow, et al, eds, Kluwer Academic Publishers, NY 2003, p 623-624; see also W Smith et al, J Modern Optics 52, 2253-2260 (2005).
[4] R Côté and A Dalgarno, Phys. Rev. A 62, 012709 (2000).

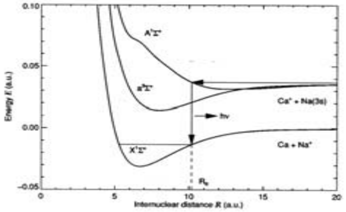
Highlights: *collisional ion-neutral sympathetic cooling is a general method for cooling molecular ions* as well as atomic. The dominant long-range $-C_4/R^4$ interaction leads to rate coefficients that vary slowly with T in the mK range. The cross sections for elastic scattering, spin-exchange, etc. are ~10^6 atomic units and are of universal character.

Goal: probe fundamental physics of ion-neutral sympathetic cooling: trapped atomic/molecular ions (*in a linear Paul r.f. trap*) collide with ultracold trapped atoms from a MOT, in overlapping volumes, in a hybrid ion-neutral trap.

Schematic of Hybrid Trap Apparatus



Example of Proposed Photoassociation Experiment



Other planned expts[3]:

1) Translational cooling of atomic and molecular ions in the hybrid trap.

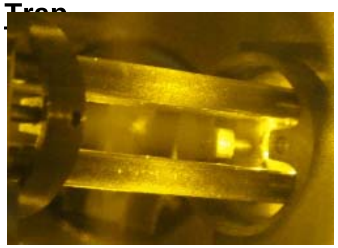
2) Internal rovibrational cooling of Na_2^+ using cold Na atoms.

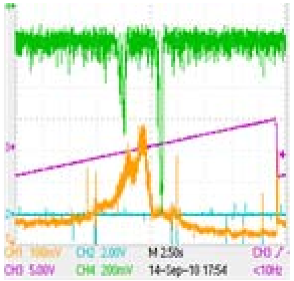
3) Possible decoherence expts. on $^{40}Ca^+$, $^{41}Ca^+$.

Progress to date:

Paul Linear r.f. Ion Trap

MOT->





Type I and II MOT loading & Saturation Spectrum