New optical methods of cooling and manipulating atoms and molecules

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Cooling and trapping of atoms with light provides us with samples far colder and denser than possible by any other means and enables us to study and control these systems in exquisite detail[1]. We can not only learn about these systems, but can devise experiments of such precision that we test the underlying physics. It is unfortunate therefore that the most effective techniques − Doppler cooling and the Magneto Optical Trap − rely on a simple energy level structure found only in a handful of elements.

One can of course trap ions using electric (and magnetic) fields regardless of their internal structure, but this is typically followed by laser cooling and one is again restricted to only a few elements. There exists an alternative class of techniques which obtain a cold sample by discarding all but the slowest particles in a distribution, but these cannot approach the temperatures and densities routinely found in a MOT.

We are interested in extending the range of species which can be optically cooled and trapped by moving away from monochromatic continuous illumination with carefully detuned light, to illumination with light shaped either temporally or spatially.

A clear example of how a pulse sequence can cool a sample is interferometric cooling[2]. Here, using no more than two $\pi/2$ pulses (and optionally two π pulses for spin-echo) one constructs a Ramsey interferometer which is sensitive to momentum. The probability of absorption depends now on the accrued phase difference between two paths, rather than on the detuning from a resonance as in Doppler cooling. Crucially, this is not restricted to atoms with a closed level scheme, but requires only that the particle have two distinct bands between which a spectrally broad $\pi/2$ pulse (or equivalent[3]) can create a superposition. We have shown this scheme can be extended to more general pulse sequences[4], and we intend to demonstrate these experimentally.

Finally, I will present an approach in which a particle can be cooled using the dipole, rather than the scattering, force. The dipole force is conservative, but by allowing the potential to vary in time, one can change the energy of a trapped particle. Specifically, if the potential depends on the position of the particle with some time delay, we can create a friction-like force[5, 6], and we are currently building an experiment to demonstrate this effect. This technique is not restricted to atoms with a simple structure, but requires only that the particle be polarisable; in principle, therefore, it can be extended without significant change to direct optical cooling of molecules.

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