MAGNETO-OPTICAL TRAP FOR METASTABLE HELIUM

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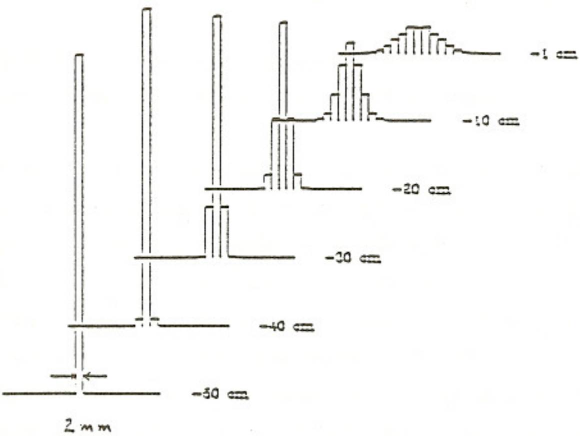
We have operated a magneto-optical trap[1] for Helium atoms using the 1.08 µm transition between the metastable 2^3S_1 and the 2^3P_2 levels. The trap, formed at the center of a pair of anti-Helmholz coils, is loaded continuously from an atomic beam cooled longitudinally by the Zeeman tuning technique. The supersonic He beam runs at 30 K and is excited by parallel electron bombardment. The design of the trap is similar to that of Ref. 2 in that the cooling laser serves as one of the six beams of the trap. In our trap, however, the cooling laser beam is not retro-reflected, but is instead focussed on the nozzle and counterbalanced by a separate beam which propagates at a 3° angle to the atomic beam axis. The six trap beams have intensities of 1 to 4 mW/cm^2, and are all at the same frequency. The atomic beam is also compressed in both transverse dimensions using Doppler cooling. For the transverse cooling we use a 1 cm interaction region, a laser intensity of approximately 1 mW/cm^2 and a detuning of 4 natural linewidths (natural width = 1.6 MHz). This cooling increases the usable density of our beam by a factor of 10. We achieve a beam rate of about 10^6 atoms/s at velocities below 400 m/s.

We perform experiments by detecting the ions formed by Penning ionization of the residual gas in the vacuum chamber, or by imaging the fluorescence of the trapped atoms using a cooled CCD camera. The trap works using detunings as large as 25 MHz. By changing the detuning and magnetic field gradient (10-30 G/cm) its diameter can be varied between 300 µm and 7 mm. When the trap density is below about 10^7 cm^{-3}, the trap lifetime is limited to about 500 ms by our vacuum of 10^{-7} mbar. At higher densities we observe a much faster, non-exponential decay of the ion rate from the trap. We believe that this decay is caused by Penning ionizing collisions between the cold He atoms in the trap. The extremely large rate coefficient we observe (of order 10^{7}cm^{-3}s^{-1}) may be due to collisions between 2^3S_1 and laser excited 2^3P_2 states. These two states collide on a $1/r^3$ potential, instead of the $1/r^6$ potential characteristic of S state collisions, and that could account for the large rate constant[3]. This observation is very important because it demonstrates a severe limit to the density achievable in a magneto-optical trap for metastable He.

Our data indicate that we only load of order 10% of the cooled atoms into the trap. To investigate this further we have performed simple Monte Carlo simulations of the cooling in the magnet. We find that the beam expands dramatically in space during slowing. In the figure we show the spatial distribution of the beam at various points in the slowing magnet. The calculation shows that the beam has a diameter of roughly 1.5 cm just before it enters the trap region. We believe that this limits the efficiency with which we are able to load the trap. The spread in position space is simply too large to capture all the atoms. This is in contrast to the situation in heavier atoms such as neon where nearly 100% loading efficiency has been reported[4]. The difference in the two situations is recoil velocity of He and Ne (9 cm/s and 3 cm/s respectively). The identical simulation run for an atom with the recoil velocity of neon gives only a few mm expansion of the beam. It is also possible that optical pumping by the laser opposed to the slower may affect our loading efficiency[4].



Monte Carlo simulation. Position distributions of He atoms are shown as a function of longitudinal position in slowing magnet. The longitudinal position noted is measured from the center of the trap. Each histogram bin corresponds to 2 mm in the transverse direction.

Our results show that we can produce a compact source of cold atoms for further experiments. Because of collisions, the achievement of high densities comparable to those achieved for alkali atoms[1] may prove difficult. The collisions, however, will allow us to investigate the behavior of Penning ionization of metastable He in a regime where quantum threshold effects should be important[3].

1. E. Raab, M. Prentiss, A. Cable, S. Chu and D. Pritchard, Phys. Rev. Lett. 59, 2631 (1987).
2. F. Shimizu, K. Shimizu and H. Takuma, Phys. Rev. A39, 2758 (1989).
3. P. Julienne and F. Mies, J. Opt. Soc. Am. B6, 2257 (1989).
4. F. Shimizu, K. Shimizu and H. Takuma, Opt. Lett. 16, 339 (1991).