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Vibrational relaxation of ultracold lithium dimers

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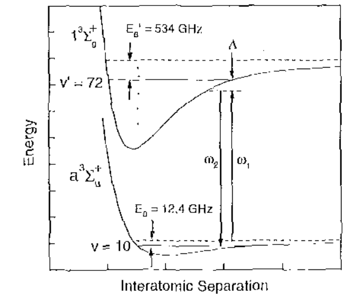
Laser cooling and trapping of atoms has enabled some of the most exciting recent advances in atomic physics, including the achievement of Bose–Einstein condensation (BEC). Efforts are now underway to trap ultracold molecules in order to study chemical reactions and to investigate BEC of larger particles. In the atomic BEC experiments, the atoms are cooled to sub-μK temperatures so the energy spread of the atoms which are not in the condensate is small ($\lesssim$20 kHz) and that of the condensate itself is zero. Therefore, a quantum degenerate gas enables an unprecedented level of spectroscopic precision.

We report two-photon photoassociation of quantum degenerate ^{7}Li atoms into the least-bound vibrational level of the ground-state triplet potential of $^7Li_2$. These molecules are magnetically trappable by virtue of their electronic magnetic moment. A gas of magnetically trapped ^{7}Li atoms is evaporatively cooled to a temperature of ~800 nK with ~10^6 atoms.[1] Under these conditions the gas is quantum degenerate, although because of attractive interactions between lithium atoms, the fraction of condensate atoms is small.[2] A laser pulse containing two independently tunable frequencies, ω_1 and ω_2, is then applied to the trapped cloud, as shown in Fig. 1. The frequency ω_1 is detuned from the free-bound transition frequency by an amount Δ while ω_2 is tuned around the two-photon resonance. The frequency difference $\delta\omega = \omega_2 - \omega_1$ is maintained with sub-Hz precision by phase-locking the difference frequency of two diode lasers. The spectroscopic lineshape will reflect the rate for vibrational relaxation resulting from inelastic collisions between atoms and molecules.

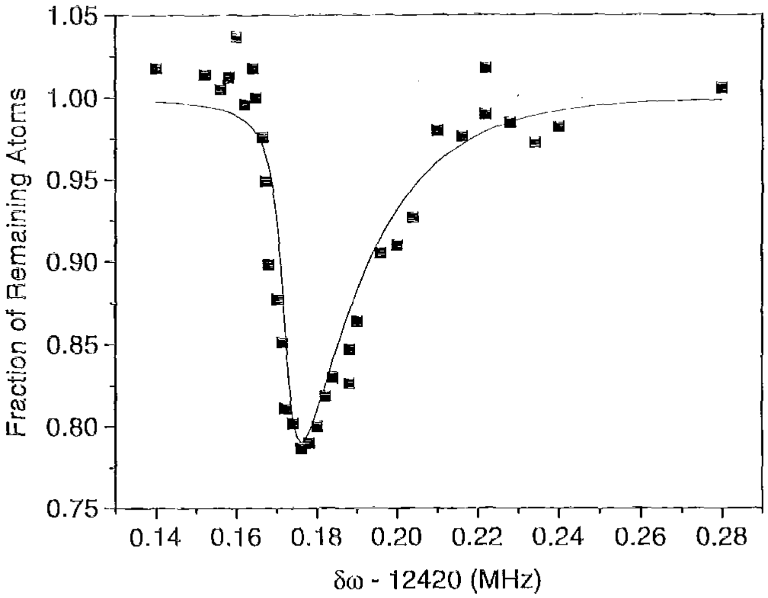


QWB2 Fig. 1. Molecular potentials and energy levels for the stimulated two-photon photoassociation described in this paper. Binding energies, E_B, are relative to the dissociation limit of the corresponding potential.

Figure 2 shows the fractional number of atoms remaining in the trap, following the laser pulse, as a function of $\delta\omega$. The asymmetric lineshape is a consequence of the convolution of the thermal energy distribution with the Lorentzian lineshape due to vibrational relaxation. The result of a fit to the measured lineshape is shown in Fig. 2 as the solid line and fits to a temperature of 800 nK and Lorentzian linewidth of 5 kHz. Assuming a Gaussian density distribution for the trapped atom cloud gives a rate constant of 4×10^{-8} cm^{3}s^{-1}. This value must be taken to be an upper limit for the vibrational relaxation rate, the contribution to the width by power broadening has not yet been determined.

The relaxation rate may prove to be small enough to permit further evaporation of the molecules. In any case, the same two-photon method can be used to convert an atomic BEC with repulsive interactions directly into a molecular condensate. The attractive case is also interesting because of the possibility that either the atom-molecule or molecule-molecule interactions are repulsive. In the former situation, a phase-separation between the molecular and atomic gases might develop or possibly the atomic condensate might be stabilized. In the latter situation, a large molecular condensate could be rapidly converted to an atomic one that will immediately undergo collective collapse due its attractive interactions.[3]

1. C.A. Sackett, C.C. Bradley, M. Welling, R.G. Hulet, App. Phys. B **65**, 433 (1997).
2. C.C. Bradley, C.A. Sackett, R.G. Hulet, Phys. Rev. Lett. **78**, 985 (1997).



QWB2 Fig. 2. Two-photon photoassociation spectrum of the v = 10 vibrational level in the $a^3\Sigma_u^+$ molecular potential. The dark squares are the normalized data obtained as described in the text and the solid curve is a fit using the thermal-Lorentzian convolution. The fit corresponds to a temperature of 800 nK and a Lorentzian width of 5 kHz.

3. C.A. Sackett, J.M. Gerton, M. Welling, R.G. Hulet, Phys. Rev. Lett. **82**, 876 (1999).