Sub–harmonic Raman resonances in cold trapped atoms

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In far off resonance optical traps it is possible to shelve cold atoms away from many perturbing factors and to perform experiments in a very controlled fashion. In our laboratory we have trapped rubidium atoms at sub-Doppler temperatures in the waist of a CO_2–laser beam emitting at 10.6 μm [1]. This kind of potential offers trapping times comparable with magnetic traps [2] with negligible decoherence rate, as the expected photon scattering time is over 5 minutes. In contrast to magnetic traps, it allows for the simultaneous trapping of all magnetic sub–levels of ground states and, for most atoms, also of all sub–levels of the first excited state.

Here we report on the observation of higher order Raman transitions between magnetic sublevels of the lowest hyperfine ground state in our far–detuned dipole trap. A small magnetic field is applied to remove the Zeeman degeneracy. Depending on the applied magnetic bias field, it is possible to observe sub-harmonic Raman resonances (*i.e.*transitions at integer sub-multiples of the magnetic sub-levels splitting) with extremely sharp lines.

Our experimental set-up has been already described elsewhere [3]. Up to 30 W of radiation at 10.6 μm from single mode CO_2–laser is focused to a waist of 50 μm inside a vacuum chamber. Atoms of ^{87}Rb are loaded from a dark magneto-optical trap (MOT) superimposed on the beam waist. After switching off of the MOT fields, atoms are left in the non–dissipative dipole potential created by the CO_2–laser. At 30 W of laser power we typically load around 5×10^6 atoms into the dipole trap with a temperature of roughly 50 μK. After applying a magnetic bias field the trapped atoms are optically pumped into the F=1,M_F=+1 magnetic sublevel of the ground state. We then induce a stimulated Doppler-insensitive Raman transition to the F=1,M_F=0 magnetic sub-level by irradiating the atoms with "Raman beams" using Blackman pulse shapes. The two "Raman beams" with orthogonal linear polarisation are copropagating along the magnetic field axis. The two beams are generated by sending the output of a Ti:Sapphire laser through two acousto–optic modulators (AOM) driven by two phase–locked oscillators. The frequency of the laser is detuned 22 GHz to the red of the D_2 transition manifold and both beams (beam waist 2mm) contain typically 250mW of total power. By scanning the frequency of one of the two AOMs it is possible to vary the frequency difference δ_r of the two Raman beams. The population of the F=1, M_F=0 sub-levels of the ground state is then detected by first transferring it selectively to the F=2 hyperfine level with a microwave π-pulse and then recording the fluorescence after applying a optical pulse on the F=2 to F'=3 cycling transition of the D2-line.

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A typical spectrum with an applied bias field of 50 kHz is shown in Fig.1A. As can be seen, resonances appear when δ_r equals w_0/n with w_0 being the Zeeman shift of the sub-levels and n an integer number. We attribute these resonances to multi-photon transitions between the ground state sub-levels as shown schematically in Fig.1B for $n = 3$. We have also observed that for a given power and detuning of the Raman beams more sub-harmonics appear when the Zeeman splitting w_0 is decreased. A simple minded view of this phenomena is that when the sub-levels are close together there is always an intermediate level close by for the multi–photon transition. Note that the effect of the AC-Stark shift induced by the Raman beams becomes less evident as the n is increased. This behaviour has already been observed in transverse optical pumping [4]. Also the lines become narrower the larger the n; let us point out that this lines for $n > 2$ become narrower than the width corresponding to the Fourier transform of the pulse envelope. This demonstrates that it is not the Fourier width of a single photon, but rather that of the combined multi–photon field, that determines the spectral width of the multi–photon transition.

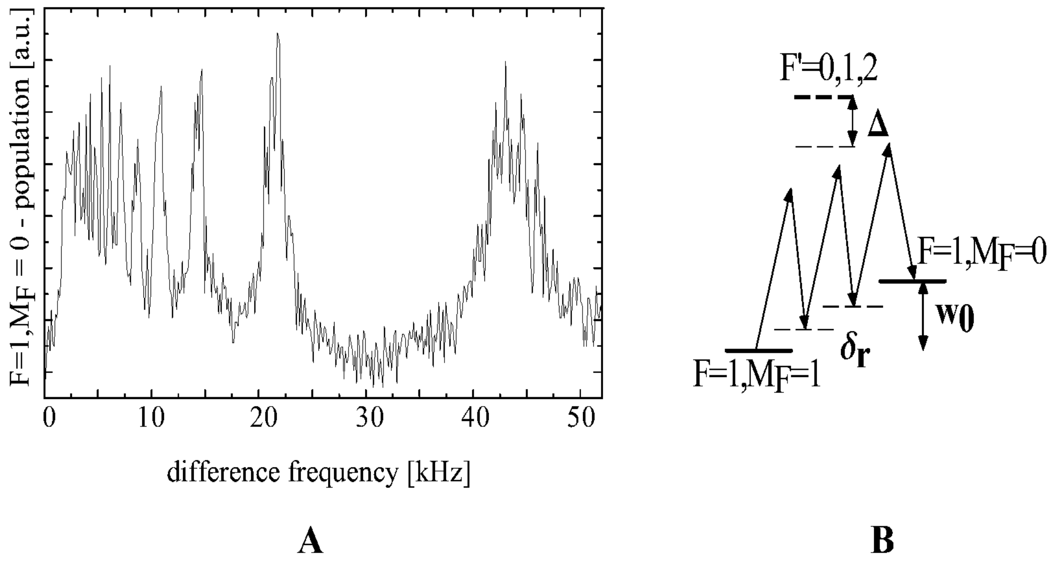

Figure 1: (A) F=1, M$_F$=0 population after the Raman transition as a function of the frequency difference δ_r of the two Raman laser beams. (B) Diagram of the two magnetic sub-levels F=1,M$_F$=1 and M$_F$=0 showing schematically a multi–photon Raman transition with $3\delta_r = w_0$ with w_0 being the Zeeman shift of the sub-levels.

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