Dynamics of Trapped Atomic Bose Condensed Systems with Three-Body Recombination for Large Scattering Lengths

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We analyzed the dynamics of trapped condensed ^{85}Rb systems with atomic losses due to three-body recombination in the regime of large scattering lengths. The fitting of the experimental data from Claussen *et al.* [Phys. Rev. Lett. 89 (2002) 010401] results in a generally large recombination coefficient which can indicate a coherent effect in the recombination process (atomic laser effect).

We have investigated the dynamics of Bose-Einstein Condensates (BEC) in the regime of large two-body scattering lengths ($a \sim 1000 a_0$, where a_0 is the Bohr radius), by studying the validity of the generalized mean-field Gross-Pitaevskii equation (GPE). The mean-field approximation has been extended to include dissipation from three-body recombination [1], and a variable scattering length, due to an external time dependent magnetic field pulse. Such a pulse generates a wide range of values for a, near a Feshbach resonance [2] of the atomic species. So, one can reach both regimes of attractive and repulsive two-body effective interactions [3,4]. Studies of BEC decays have been widely investigated [5,6] in the literature. Recently [4], BEC experiments with large positive atom-atom scattering lengths (a), i.e., strong repulsive two-atom pseudo-potential, were probed by means of magnetic field pulses. It was used triangular and trapezoidal shapes for the pulses and very short time intervals, ranging from about 10μs to $\sim$200μs, near the Feshbach resonance of ^{85}Rb. Such pulses originate very large time dependent scattering lengths ($\sim 1000 a_0$), as shown in figure 1(a). They observed a surprising dependence of the remaining number of condensed atoms N_r on the magnetic pulse rise time t_r (the time interval in which a is being varied). They also measured the remaining fraction of condensed atoms as a function of the pulse hold time t_h (the time interval in which a is kept constant). Here, we fitted the magnitude of the three-body recombination coefficient in extended GPE to reproduce JILA data, as we will explain in detail. The three-body recombination parameter, K_3, which is proportional to a^4 [1], depends on time due to the magnetic pulse, as shown figure 1(b) for the dimensionless recombination rate, $\xi(t)$. We calculated the remaining fraction of condensed atoms (N_r/N_0) versus the pulse hold times t_h for some rise times t_r and compared our results with JILA data [4]. We follow same formalism described in [7], and used the Crank-Nicolson method to obtain the numerical solution of the extended

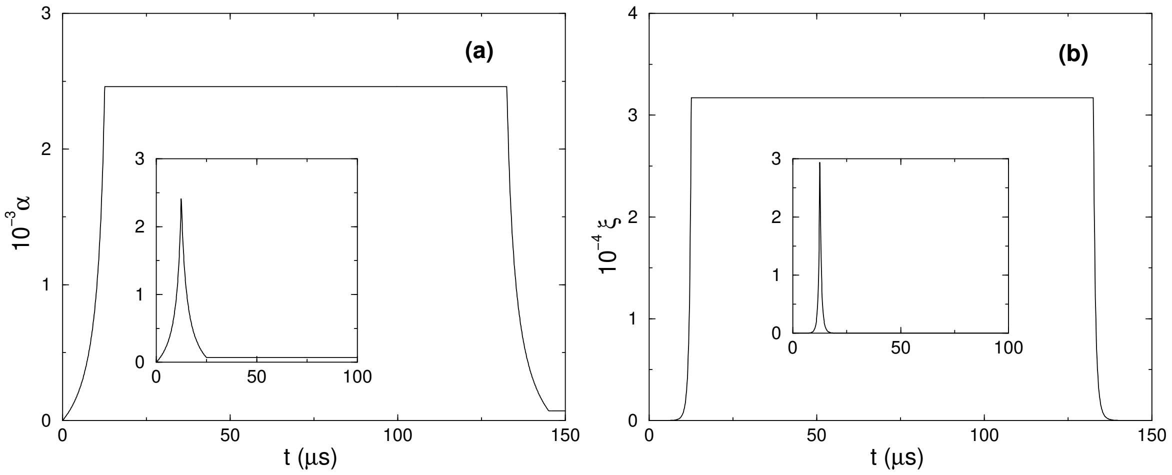

Figure 1. (a) Time dependent scattering length for trapezoidal and triangular (inset) pulses in a_0 units ($\alpha(t) \equiv a/a_0$). (b) Dimensionless three - body recombination ξ for trapezoidal and triangular (inset) pulses.

GPE. The GPE for condensates with spherical symmetry reads

$$i\hbar\frac{\partial\Psi(\vec{r},t)}{\partial t} = \left[-\frac{\hbar^2}{2m}\nabla^2 + \frac{m\omega^2 r^2}{2} + \frac{4\pi\hbar^2 a(t)}{m}|\Psi(\vec{r},t)|^2 - \mathrm{i}\hbar\frac{K_3}{4}|\Psi(\vec{r},t)|^4\right]\Psi(\vec{r},t), \qquad (1)$$

where the wave-function Ψ is normalized to the number of condensed atoms N; m is the atom mass; ω is the trap frequency; the scattering length obeys the relation

$$a = a_b \times \left(1 - \frac{\Delta}{B - B_r}\right) \quad , \qquad (2)$$

where Δ is Feshbach resonance width, B_r is the resonance field and a_b is the background scattering length; and, following Ref. [1], the recombination rate is described by the relation

$$K_3(t) \cong \kappa\frac{\hbar}{m}[a(t)]^4 \Rightarrow \xi(\tau) = \kappa\frac{a_0^2}{32\pi^2 l_0^2}\alpha(\tau)^4 . \quad . \qquad (3)$$

where κ in our calculation was determined from JILA experiment. In Ref. [1], they found $\kappa = 3.9$, which is inside the interval $0 \leq \kappa \leq 67.9$ obtained in more recent papers [6].
We have observed that for large t_r the value of κ was consistent with the theoretical predictions in the vacuum, for the upper limit of K_3, which does not occur for short t_r. We will discuss a possible scenario in order to understand these results. From the extended GPE with a κ within the theoretical interval, we can not describe the observed results for N_r against t_r, for very short pulse lengths ($\sim 10\ \mu$s). We found that the decay of the condensate for large a as a function of the pulse hold time t_h can be described if one uses κ above the theoretical upper limit, as one can see in figure 2. For large rise time (or slow variation of a), the parameter κ is consistent with the theoretical upper limit. For short rise time (or fast variation of a), we can only describe the experimental results with a large value of κ: $\kappa \cong 1800$ for $t_r \cong 12.5\mu$s. We could interpret this result as an evidence

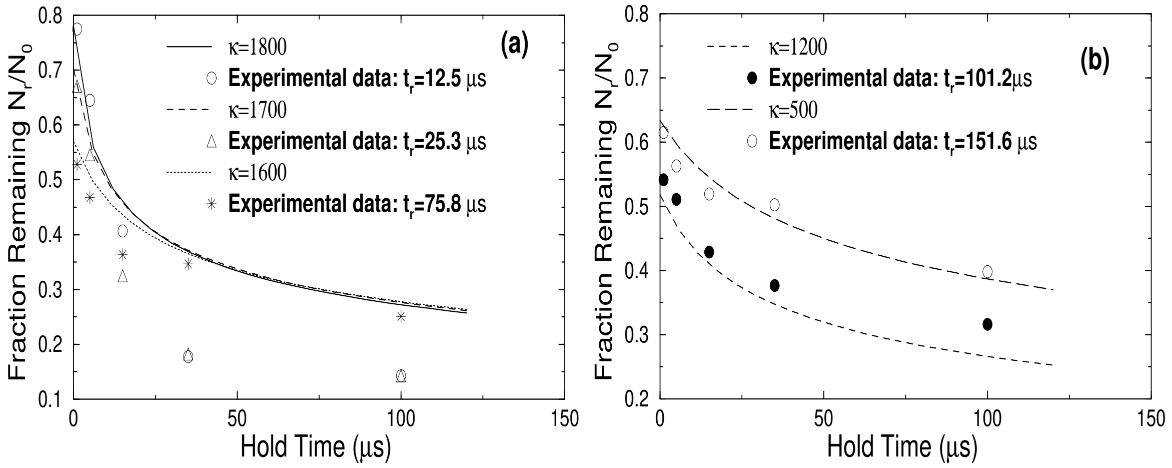

Figure 2. Remaining fraction of atoms from ^{85}Rb BEC versus the hold time of the pulses (μs) for (a) shorter rise times ($t_r < 100$) and (b) longer rise times ($t_r > 100$).

of coherence effects in the formation of dimers in the condensate with an enhancement of the dimer density and remaining atoms (atomic laser effect). The dimers are formed in a coherent process and may scape from the condensate. More details of our calculations and results can be found in Ref. [8].

In conclusion, in the case of fast variation of the positive two-atom scattering length, it is reasonable that the increase of the dimer and remaining atom densities imply in a coherent laser effect which naturally leads to large values of K_3.

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