Heating and lifetime of single atoms in microscopic dipole traps

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Quantum computing is one of the most promising technologies of resent decades. Currently there are several approaches towards the creation of scalable QC, and one of them is computer on neutral atoms [1]. In a neutral atom quantum computer alkali atoms are trapped in laser latices inside vacuum chambers. Each atom acts as a single physical qubit. More specific, two energy levels of hyperfine structure represents a qubit. Single qubit gates are performed by applying laser pulses. CNOT gate is based on the phenomena of dipole blockade: if one atom is in Rydberg state, energy levels of atoms nearby will shift due to dipole-dipole interaction.

It's obvious that coherent time of physical qubit cannot exceed the time of atom being trapped. Lifetime of atom in the trap is limited by several reasons. On the one hand, vacuum chambers cannot be fully pumped out, so there are always some amount of residual gas. Molecules of residual gas are constantly collide with chamber walls and therefore exchange energy with it (we can assume, that kinetic energy of residual atoms is at magnitude of kT with $T \approx 300K$). Most atomic traps have potential wells equivalent to $T \approx 100mK$, so almost all collisions with residual gas will led to atom loss. On the other hand, intensity of trap laser fluctuates in time, which leads to oscillations of potential well depth. More over, mechanical noises in optical scheme cause fluctuations of the position of the well. This leads to resonant heating of the trapped atom, so it eventually exceed the well depth [2].

In this work we experimentally study the lifetime of single atoms in a microscopic dipole trap and propose an experimental procedure based on pulsed cooling to mitigate heating due to intensity fluctuations of the trapping laser and to obtain vacuum limited lifetimes.

Experiment 1

In the first experiment we've studied the total effect from both heating and residual gas collisions with the following experimental sequence:

1. Atom is loaded to the dipole trap via magneto-optical trap
2. MOT is turned off for time T
3. After T presence of the atom is checked detecting photons scattered from it.

This sequence was repeated 200 times for each T in $[0, 75]$ seconds. By dividing the number of successful experiments over 200 the probabilities of finding an atom were estimated (shown on fig. 1).

Experiment 2

Later we've modified the experimental sequence to eliminate laser noise heating. Lasers used to detect an atom are part of cooling system, so each time they are turned on, atom loses part of it's kinetic energy [3]. In that experiment not the probability of finding an atom is measured, but the exact lifetime of each trapped atom by the following algorithm:

1. Atom is loaded to the dipole trap, lifetime counter is initialized to zero
2. MOT is turned off for time t
3. After t MOT lasers are turned on for a small time to cool the atom. By the scattered photons the presence of atom is checked. If atom is in the trap, lifetime counter is incremented by t and experimental sequence returns to step 2. Otherwise, the current value of lifetime counter is saved and the experiment is repeated from the beginning.

From that experiment we've obtained the distribution of atom lifetime in the trap. By cumulative summation of that distribution the probabilities similar to data from the first experiment were calculated 2.

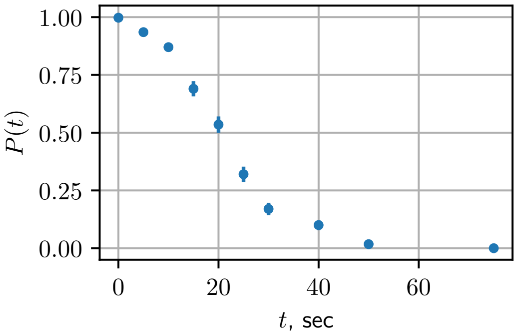

Figure 1: Probability of finding an atom in the trap after time t.

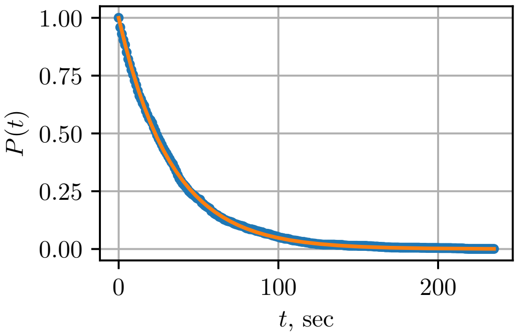

Figure 2: Probability of finding an atom in the vacuum-limited trap.

Thereby, our experimental data suggests that the atom lifetime in our trap is far from being vacuum-limited. The heating mechanisms are investigated, with the most likely candidate being dipole trap laser noise. Data from the second experiment were fitted by $P(t) = e^{-t/\tau}$ with estimated $\tau = 32.94 \pm 0.06$ seconds.

References

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