On the Possibility of Deep Laser Cooling of Magnesium Atoms with Large Ultracold Atomic Fraction

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Laser cooling of neutral atoms has found numerous relevant applications such as Bose-Einstein condensation, quantum informatics, atomic nanolithography and interferometry. Especially, laser cooling and trapping have great prospects for modern metrology, promising unprecedented accuracy of frequency and time standards[1].

For a few reasons, the main candidates for producing a new-generation frequency standards are alkaline earth and alkaline-earth-like atoms: Yb, Ca, Sr, Hg and Mg. To date, atoms of the first four elements can be effectively cooled down to the recoil energy limit and even below to obtain the Bose-Einstein condensate (BEC). But long time researchers have not been able to reach the same success with Mg. At the same time, magnesium atoms have some advantages. For instance, the black body radiation (BBR) shift of the clock transition in magnesium is smaller in respect to the other candidates. The strong dipole transition $3^1S_0 \rightarrow 3^1P_1$ with very short lifetime of the exited state and absence of the optical pumping on the nonresonant level 3^1D_2 (in contrast to Ca and Sr) allow one to realize the first cooling stage very effectively[2,3]. Recently some positive experimental results in magnesium cooling have been achieved in the Hannover University[4]. The authors used $3^3P_2 \rightarrow 3^3D_3$ dipole transition for laser cooling and a dipole trap for collecting the ultracold atoms in vicinity of a magneto-optical trap (MOT). However, only a small number of ultracold magnesium atoms ($N_{ultra} \approx 5000$, $T \approx 5$ μK) was confined in a dipole trap.

In our work we propose an approach to greatly increase the fraction of ultracold atoms in a cloud of cold atoms in MOT. Detailed theoretical analysis of sub-Doppler laser cooling of ^{24}Mg atoms in 1D configuration is presented. The atomic velocity distributions are gained beyond the limits of slow atoms approximation and for arbitrary light field intensity. The absence of these limits allows us to determine the optimal parameters of light field to maximize a fraction of ultracold atoms ($T \approx 5$–10 μK). In particular, at certain conditions the fraction can reach a value of 50% ($N_{ultra} \sim 10^5$–10^6). Large number of ultracold atoms is very important for many applications and fundamental experiments (e.g., quantum metrology based on the optical lattices, BEC and so on).

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