On Efficiency of Laser Pumping for Selective Hyperfine-Level Population in Cesium Atom

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The results of theoretical studies of the laser pumping of the lower sublevel $6^2S_{1/2}$ F_g=3M=0 for the "clock" transition in a cesium frequency standard are presented. The pumping transitions F_g (or F_f) $\leftrightarrow$ F_e induced by a linearly polarized laser field in an open three-level atomic system (e.g., $6^2S_{1/2}$ F_g=3, F_f=4 and 6^2P_J F_e=3 or F_e=4) are considered. The Liouville equation and the kinetic balance equations have the same asymptotic solution for the final sublevel populations[1]:

$$\bar{n}_{F_{f(g)}M} = n^0_{F_{f(g)}M} + \sum_{M'\neq\bar{M}} P_{MM'}(F_{f(g)}, F_{g(f)}) n^0_{F_{g(f)}M'},$$
$$\bar{n}_{F_{g(f)}\bar{M}} = n^0_{F_{g(f)}\bar{M}} + \sum_{M'\neq\bar{M}} P_{\bar{M}M'}(F_{g(f)}, F_{g(f)}) n^0_{F_{g(f)}M'},$$

where

$$P_{MM'}(F_{f(g)}, F_{g(f)}) = \sum_{M''\neq\bar{M}} b_{MM''}(F_{f(g)}, F_e)[(\mathbf{1} - \mathbf{b}(F_{g(f)}, F_e))^{-1}]_{M''M'},$$

n^0_{FM} is the initial sublevel population, $b_{MM}(F,F_e)$ is the radiation decay ($F_eM' \rightarrow FM$) branching coefficient, and $\bar{M}$ is the magnetic quantum number for forbidden laser-induced transitions. The laser parameters determine the effective time of the pumping process.

The following series of successive pumping transitions of the D_2 line (J=3/2) are considered for the initial equilibrium state: (i) $F_f \leftrightarrow F_e$=3 transitions with σ- and π-polarized fields, (ii) $F_f \leftrightarrow F_e$=4 and $F_f \leftrightarrow F_e$=3 transitions with π-polarized fields. Both series provide almost total depopulation of the level F_f and the increase of the F_gM=0 sublevel population by the factor 2.5. After the further pumping transition $F_g \leftrightarrow F_e$=3 the population efficiency for the F_gM=0 sublevel rises to the value 6, and even to 9.3 after the intermediate σ-polarization pumping $F_g \leftrightarrow F_e$=2.

At the simultaneous bichromatic π-polarization pumping by the $F_g \leftrightarrow F_e$=3 and $F_f \leftrightarrow F_e$=4 transitions (D_2 line) the initial F_gM=0 sublevel population increases to the factor 11.3 after depopulation of the F_fM=0 sublevel in the subsequent $F_f \leftrightarrow F_e$=3 transition.

The results show that the optical pumping makes possible a significant increase of the signal-to-noise ratio in modern cesium frequency standards. This approach is applicable for optimization the pumping efficiency of other atoms, in particular, for the fountain-type rubidium atomic standards with the unique long-term stability[2].

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[1] A.I. Magunov, V.G. Palchikov, "Laser selective pumping of magnetic hyperfine sublevels in cesium atom", JETP, vol. 118, n. 4, 2014.

[2] Yu. Ovchinnikov, G. Marra, "Accurate rubidium atomic fountain frequency standard", Metrologia, vol. 48, p. 87-100, 2011.