Spontaneous-emission transfer of coherence induced by elliptically polarized light in unclosed optical transitions

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The light-induced coherence of atoms plays a key role in quantum optics, polarization nonlinear spectroscopy, polarization stability of gas laser, polarization gradient laser cooling of atoms, formation of optical lattices, resonant fluorescence , et al. Analysis of two-level closed atomic transitions shows that due to the angular momentum exchange between the elliptically-polarized light and atoms a long-term living macroscopic anisotropy (multipole momenta of atoms) in a ground state is induced.

However, the majority of atomic transitions are unclosed (open) (Fig. 1), i.e. atoms, being excited by resonant polarized light from the manifold of ground-state magnetic sublevels $\{|F_a, m_a\rangle\}$ into the upper states $\{|F_b, m_b\rangle\}$ can spontaneously decay and the light-induced coherence will be transferred onto another ground or metastable level $\{|F_c, m_{b_c}\rangle\}$ (e.g. $\{|F_a, m_a\rangle\}$ and $\{|F_c, m_c\rangle\}$ are the hyperfine components of the ground level), where F_a, F_b, F_c are the angular momenta of levels and m_a, m_b, m_c are their magnetic projections. In the final stage of interaction process at $t \to \infty$ all atoms or some fraction of them will be eventually pumped on the level (c) and they will not interact with light.

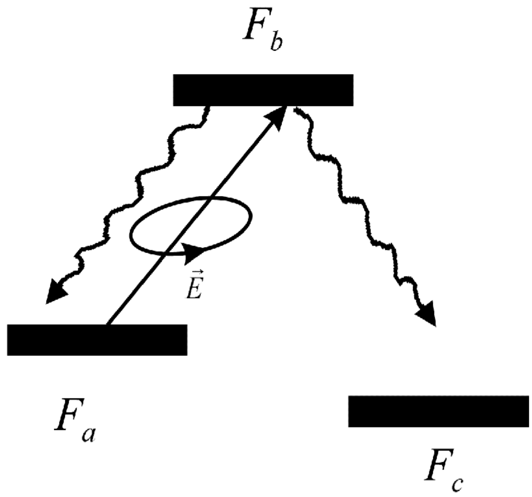

Figure 1: The scheme of unclosed transition driven by elliptically polarized field $\vec{E}$. Each level is degenerated on projections of momentum $-F_i \le m_i \le F_i$ $(i = a, b, c)$.

In the present work we analyze the steady state of such three-level atoms under their interaction with resonant elliptically polarized light in open optical transitions. We have found the exact analytical solutions of this problem for arbitrary elliptical polarizations of light fields and different types of the transitions. Namely:

1. For the $F_a = F \leftrightarrow F_b = F \rightarrow F_c = F + \Delta F$, ($\Delta F = 0, \pm 1$) transitions ($F$ is a half-integer) all atoms will be repumped from $\{|F_a, m_a\rangle\}$ states into the $\{|F_c, m_{b_c}\rangle\}$ states with isotropic distribution of populations over magnetic sublevels independently on the light polarization.

2. For the dark $F_a = F \leftrightarrow F_b = F-1 \rightarrow F_c = F+\Delta F$, ($\Delta F = 0, -1, -2$) transitions, where coherent population trapping takes place [1], the stationary distribution of population over the states $\{|F_c, m_c\rangle\}$ of the level (c) is also isotropic, while on the level (a) the fraction of atoms $2N_a$ is trapped into the two equally populated elliptical dark states $|\Psi_i^{(NC)}\rangle$ [1, 2] with anisotropic distribution of populations and nonzero coherence of magnetic sublevels

$$\langle F_a, m_a|\widehat{\rho^{aa}}|F_a, m_a'\rangle = N_a \sum_{i=1,2} \langle F_a, m_a|\Psi_i^{(NC)}\rangle\langle\Psi_i^{(NC)}|F_a, m_a'\rangle\,, \quad N_a = \frac{\gamma_{ba} + \gamma_{bc}}{2\gamma_{ba} + \gamma_{bc}(2F+1)}$$

   Where γ_{ba} and γ_{bc} are the probabilities of spontaneous decay of the level (b) on channels $b \rightarrow a$ and $b \rightarrow c$, correspondingly.

3. The $F_a = F \leftrightarrow F_b = F \rightarrow F_c = F + \Delta F$, ($\Delta F = 0, \pm 1$) transitions with F an integer are analyzed for the particular case $F = 1, 2$. As a result of coherent population trapping on the level (a) is formed one elliptically polarized dark state, in which an atom does not interact with pump field. In this case due to spontaneous emission some fraction of atoms will be transfered onto the level (c) with anisotropic distribution of populations over magnetic sublevels and nonzero Zeeman coherence.

4. In the case of bright $F_a = F \leftrightarrow F_b = F+1 \rightarrow F_c = F+\Delta F$, ($\Delta F = 0, 1, 2$) transitions in arbitrary elliptically polarized field all atoms from level (a) will be transfered onto level (c). The analytical expressions for density matrix of level (c) are found for transitions with $F = 0, 1$.

Note that in all cases the stationary anisotropic states of levels are governed by the parameters of light ellipticity only and they are independent of intensity and frequency of driven field.

Thus, the manipulation of light polarization makes it possible to prepare atomic levels in a given stationary state of anisotropy, including the liht-induced coherence between magnetic sublevels.

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[2] Milner V., Prior Y., *Phys. Rev.Lett.* **80** 940 (1998).