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Coherent trapping of a three-level atom in a circularly polarized light

Li-Xin Xia [a,b,c,*], Guo-Jian Yang [a]

[a] Department of Physics, Beijing Normal University, Beijing 100875, People's Republic of China
[b] Department of Technology, Hunan Normal University, Changsha 410081, People's Republic of China
[c] Department of Physics, Hunan University of Science and Engineering, Yongzhou, Hunan 425006, People's Republic of China

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Abstract

Using semiclassical theory, we study coherent trapping of a three-level atom, where the atom possesses a momentum of its center-of-mass motion and is irradiated only by a classical circularly polarized electromagnetic wave. We find that if the atom is initially in a coherent trapping state of it, under the zero- or first-order approximation, the atom is absolutely or nearly in the state hereafter.

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1. Introduction

An interesting phenomenon in which a coherent superposition of atomic states is responsible for a novel effect is coherent trapping. If an atom is prepared in a coherent superposition of atomic states, it is possible to cancel absorption or emission under certain conditions, so that we call this state coherent trapping state. These atoms are then effectively transparent to the incident field even in the present of resonant transitions.

There were many works [1–9] devoted to the coherent trapping of a three-level atom by considering the interaction between a three-level atom (with or without a momentum of center-of-mass motion) and two

* Corresponding author. Tel./fax: +867466381254.
E-mail address: xialixin@hunnu.edu.cn (L.-X. Xia).

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electromagnetic (e.m.) fields (classical, quantum, or one classical and another quantum). Scully and Zubairy [5] studied the effect of coherent trapping for a resting three-level atom interacting with two classical e.m. field. Arun and Agarwal [6] investigated dark states of ultra-cold three-level atoms with its quantized motion of center-of-mass interacting with two quantum field in cavity. Kuang and Zhou [7] presented generation of atom–photon entangled states and dark states using two fields (one classical field and another quantum field) and the resting atoms. Enaki et al. [8,9] studied the interaction between the single-mode quantum cavity field and an atomic string consisting of three-level atoms, and obtained the trapping conditions. In addition, the properties of the e.m. field are examined, such as vacuum nutation, sub-Poissonian statistics and squeezing properties.

In this paper, we also study the coherent trapping of a three-level atom. However, we consider the center-of-mass motion of the atom and use only a single classical circularly polarized e.m. wave.

Usually, the used light is either plane or circularly polarized in treating the interaction of three-level atom with e.m. field. Nevertheless, in order to obtain the same result, for plane-polarized light both the dipole approximation and the rotating-wave approximation are required, whereas the circularly polarized light exploits only the dipole approximation. For simplicity, in the work we adopt the circularly polarized light instead of the plane-polarized light. Based on semiclassical theory, we show that there exists a coherent trapping state in the system, a special coherent superposition state composed of two forbidden–transition atomic states. If the atom is initially in this state, under the zero-order approximation ($\Delta = 0$) the atom is in the state at any time and its occupation probabilities in other states are always zero. Similarly, under the first-order approximation ($\Delta \neq 0$) the atom is nearly in the state, while its occupation probabilities in the other states is nearly zero.

This paper is organized as follows. In Section 2, we derive the Schrödinger equation (in which the center-of-mass motion of the atom is treated quantum mechanically) [10]. In Section 3, we show the coherent trapping of the atom under the zero- and first-order approximations. Finally, a brief conclusion is given in Section 4.

2. The Schrödinger equation

We consider a three-level atom of mass m and the dipole moment $\mathbf{D}$. The atom moves initially in the z-direction with a momentum p_0, and is irradiated by a circularly polarized e.m. wave with the wave vector k and angular frequency ω_L. The e.m. wave propagates along the positive z-direction, and its electric field $\mathbf{E}$ assumed to be of the form $\mathbf{E} = (E_x, E_y)$, $E_x = A\cos(\omega_L t - kz)$, and $E_y = A\sin(\omega_L t - kz)$, where A is amplitude of $\mathbf{E}$. Accordingly, the Hamiltonian of the three-level atom is given by [10]

$$H = \frac{P^2}{2m} + H_0 + H_I, \tag{1}$$

where $P^2/2m$ is kinetic energy associated with center-of-mass momentum along the z-direction, $H_0 = \mathrm{dig}(E_1, E_2, E_3)$ is Hamiltonian determined by the internal motion of the atom, and $H_I = -\mathbf{D}\cdot\mathbf{E}$ is dipole interaction energy between the atom and the e.m. wave.

It is well known that the three-level atoms have three kinds of structures, that is, the so-called Λ-type, V-type and Σ-type. We assume that for these three kinds of atoms, the dipole-allowed transitions occur only in levels 1 and 2 as well as 1 and 3. These transitions are shown by the lines with arrows in Fig. 1. We start our study with the Schrödinger equation

$$i\hbar\frac{d}{dt}|\psi\rangle = H|\psi\rangle, \tag{2}$$