Optik 135 (2017) 118–123

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Influence of atomic mass centre moving on spontaneous emission in double-well potential

Ming-Song Ding[a], Huan-Lin Lv[a], Yu-Jie Liu[a,b], Li Zheng[a,*]

[a] Information Science and Engineering College, Dalian Polytechnic University, Dalian 116034, China
[b] Institution of Theoretical Physics, School of Physics, Northeast Normal University, Changchun 130024, China

ARTICLE INFO

Article history:
Received 9 November 2016
Accepted 30 January 2017

PACS:
03.65.Yz
03.65.Ud

Keywords:
Quantum tunneling
Double-well potential
Spontaneous emission
Atomic population inversion

ABSTRACT

The interaction between a two-level atom trapped in symmetric double-well potential and a single mode cavity field is investigated. By solving Schrödinger equation, the analytical expressions of the total wave function and inversion of the atomic energy level for the whole system are given. Time evolution of the atomic population inversion is analyzed for different initial states of the cavity field, such as fock and coherent states. Influence of atomic mass centre motion on population inversion is considered. Results show that by choosing appropriate cavity field initial state, potential well location and related factors, the spontaneous emission rate of an atom can be effectively controlled and the atomic moving centre of mass can suppress Rabi oscillation.

© 2017 Elsevier GmbH. All rights reserved.

1. Introduction

The interaction between photons and matter is one of the most important academic areas. As a result of the valuable applications in the spatial localization of atoms [1], quantum information and computing [2], and so on, the atomic spontaneous emission becomes the central issue. As is well known, for atoms in free space, atomic coherence and quantum interference by Laser-induced are the basic mechanisms for controlling the spontaneous emission [3]. On the other hand, there are two alternative ways to modify and control atomic spontaneous emission. One approach is to coherently drive atoms with externally applied laser fields [4], the other way to put the atoms in photonic crystals [5,6] or in optical cavities [7]. Recently, Jin et al. propose an ultrafast non-local moulding of the vacuum field in a cavity quantum electrodynamics (CQED) system as a method to real-time control the spontaneous emission [8]. Such tunability is considered to be worthy for modifying the Rabi oscillations of the quantum system while leaving the cavity population undisturbed.

Quantum tunneling refers to a particle could tunnel through a barrier which is a fundamental physical effect [9], and the atoms trapped in potential wells have given us an opportunity to study the aspects of quantum decoherence, including coherent dynamics on macroscopic scale. The tunneling effect is considered as a feature that distinguishes the quantum world from the classical world. Since the quantum tunneling for intramolecular rearrangements in pyramidal molecules was testified in 1927 [10], it has attracted substantial attentions [11–14].

Here we investigate the phononic recoil-related decoherence of the quantum tunneling for a two-level atom trapped in symmetric double-well potential and coupled to a single mode cavity field. Because the double-well potential is symmetric,

* Corresponding author.
E-mail address: 15941121899@163.com (L. Zheng).

http://dx.doi.org/10.1016/j.ijleo.2017.01.103
0030-4026/© 2017 Elsevier GmbH. All rights reserved.

the particle tunneling through the barrier oscillates back and forth between the degenerate states. We obtain the dynamical evolutions of atomic population inversion by solving Schrödinger equation, assuming that the cavity field is prepared initially in fock or coherent state. In addition, influence of atomic mass centre motion on population inversion is considered. It is found that by choosing appropriate cavity field initial states, the atomic spontaneous emission can be effectively controlled and with the increase of width of Gaussian wave packet a, the suppression of the atomic moving centre of mass on Rabi oscillation becomes obvious.

This paper is organized as follows: In Section 2, we describe the model setup, and give the analytical expressions of the total wave function for the whole system. In Section 3, the inversion of the atomic energy level is derived, then we investigate the influence of quantum tunneling on the atomic population inversion. Finally, Section 4 gives a brief summary.

2. Model and wave functions

We consider a single two-level atom (the atomic transition frequency is ω_0 and the mass of atom ism_0) coupling with a single-mode cavity field. The atom interacts with a standing-wave cavity mode. Assume that the cavity is a symmetric double well potential $V(x)$ putted on the atom, and the atom can be regarded to bind in the y − z plane at the equilibrium position y = z = 0. This system can be written as

$$H = H_{AI} + H_{AE} + H_F + H_{AF}, \tag{1}$$

where H_{AI} and H_{AE} are supposed to be the Hamiltonian describing the external and internal degrees of atoms respectively. H_F is the Hamiltonian of the cavity field, and H_{AF} denotes the atom-field interaction. Under the rotating-wave approximation, the Hamiltonian of total system is given by

$$H_{AI} = 1/2\hbar\omega_0\sigma_z, \tag{2}$$

$$H_{AE} = p^2/2m_0 + V(x), \tag{3}$$

$$H_F = \hbar w a^{\dagger} a, \tag{4}$$

$$H_{AF} = \hbar g \sin[k(x - x_0)]\, a\sigma_+ + h.c. \tag{5}$$

where σ_z is Pauli operator, $\sigma_+ = |e\rangle\langle g|$ and $\sigma_- = |g\rangle\langle e|$ are the atomic operators with respect to the excited state $|e\rangle$ and the ground state $|g\rangle$ of the atom, $a^{\dagger}$ and a are the creation and annihilation operators of the cavity field mode k with frequenc $\omega = ck$ ($k = |\mathbf{k}|$), x_0 denotes the abscissa at the left cavity mirror ($x_0 < 0$), p and x are the atomic momentum and position respectively. Furthermore, we assume g is the atom-cavity coupling constant with

$$\hbar g = \sqrt{\frac{\hbar w}{2\varepsilon_0 V}}\boldsymbol{\varepsilon_k}\boldsymbol{d}, \tag{6}$$

we assume that V is the effective mode volume, ε_k is the polarization vector of the field vector and d is the transition dipole moment of the atom.

We define $V(x)$ as a symmetric double-well potential along the x direction with the minima at $x_L = -b/2$ and $x_R = b/2$ (b is constant number). The atomic centre of mass can be located at either of the two minima. In the semiclassical approximation, we can propose the corresponding ground state $|L\rangle$ (or$|R\rangle$) in the left (or right) well to be strongly localized in the vicinity of the corresponding potential minima.

When the depth of the double well potential is finite, the atom will transmit from one well into the other mainly due to thermal excitation for a high temperature. For the atom in a low temperature, the quantum tunneling exists and it means under the wave function approach the atom can from one side of the symmetric double-well potential to the other side. Thus the degenerate of the ground state is moved. The energy levels will be splitted into $E_{\pm} = \pm\hbar\Delta$. We consider Δ as the tunnel splitting of the double-well potential, and the eigenstates $|\pm\rangle$ can be obtained as

$$|+\rangle = \frac{1}{\sqrt{2}}(|L\rangle + |R\rangle), \tag{7}$$

$$|-\rangle = \frac{1}{\sqrt{2}}(|L\rangle - |R\rangle). \tag{8}$$

Assume that at time $t = 0$, the atom is considered in the state $|L\rangle$ initially, the corresponding wave function $\varphi_L(x, 0)$ of which is a Gaussian wave packet centered at $-b/2$ with a width of a ($a > 0$), i.e.

$$\varphi_L(x, 0) = \left(\sqrt{2\pi}a\right)^{-1/2} exp\left[-\left(x + b/2\right)^2/\left(4a^2\right)\right]. \tag{9}$$

To proceed, we assume the atomic inner state is initially in excited state $|e\rangle$. Therefore, the initial state can be written as

$$|\psi_0(0) = |n\rangle \otimes |L\rangle \otimes |e\rangle \tag{10}$$

Download English Version:

https://daneshyari.com/en/article/5025803

Download Persian Version:

https://daneshyari.com/article/5025803

Daneshyari.com