Mazer action in a bimodal cavity

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The work of Meyer, Scully, and Walther [Phys. Rev. A 56, 4142 (1997)] is generalized to study the operation of a two-mode mazer with particular reference to the question of mode-mode correlations. The explicit expression for the detailed balance steady-state photon distribution has been derived. It is shown that the two-mode mazer exhibits much stronger sub-Poissonian statistics for each mode. The photon-number distributions are found to be quite sensitive to the presence of blackbody photons in the cavity. The interferences among contributions from different dressed states enable one to obtain the phase of the transmission amplitude of finding the atom in the initial excited state by considering a set of two measurements involving two different initial states of the atom-field system.

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I. INTRODUCTION

Since the early realization [1] of micromaser, the interaction of atoms with fields in high quality cavities continues to attract a great deal of attention [2]. The operation of micromaser has been explained [3,4] and many features of the characteristics of the field in the cavity have been predicted. These include sub-Poissonian statistics [3,4], the trapping states [5], and unusual types of diffusion of the field [6]. All these characteristics depend in important manner on parameters such as atomic flux, quality factor, etc. Recently in a remarkable experiment [7] the trapping states have also been seen. The work on micromasers has been generalized in many different directions. For example, the two-photon micromaser as well as the microlaser were realized [8,9]. Further the theory was extended to three-level systems [10].

When the micromaser is pumped by ultracold (laser cooled) atoms [11], quantization of external motion of atoms becomes necessary. This quantization of center-of-mass (c.m.) motion [12,13] leads to a completely new kind of induced emission [14]. In this way, Scully et al. [14] have introduced a new concept called mazer (microwave amplification by the z motion induced emission of radiation). The quantum theory of single mode mazer operating on two-level atoms has been developed in great detail [15−17]. The steady state photon distribution of the mazer operating on two-level atoms under the resonance condition looks similar to a pair of thermal distributions one of which is shifted towards the larger photon number [14]. This state which can be viewed as a mixture of the thermal state and the shifted thermal state, has been shown to be nonclassical [18]. The work of Meyer et al. has been extended to treat the theory of single mode two-photon mazer [19]. The interaction between an ultracold A-type three-level atom with degenerate ground levels and a single mode radiation field has been studied and the effect of detunings on the photon emission probability of an excited atom has been discussed [20]. In this paper, we examine the two-mode mazer. We follow very closely the work of Meyer, Scully, and Walther [15].

The organization of the paper is as follows. In Sec. II, we study the interaction of three-level cold atoms moving through the two-mode cavity and we show the correlation between the internal dynamics and the external z motion of atoms. In Sec. III, we discuss the transmission of an atom incident on the cavity in various initial states. In Sec. IV, we derive the master equation for the reduced density matrix of the field in the cavity. In Sec. V, the steady state photon probability distribution under the condition of detailed balance is derived. In Sec. VI, the photon statistics of cavity field in a fixed mode has been discussed. In Sec. VII, we obtain the steady state photon probability distribution numerically for the case of unequal coupling constants for the two cavity modes.

II. MODEL SYSTEM AND DYNAMICS

We consider a beam of slow, monoenergetic three-level atoms with an A-type configuration passing through a high Q, two-mode microwave cavity of length L. The atomic flux is so adjusted that only one atom interacts with the cavity field at a time. The energy level diagram for the analysis is shown in Fig. 1. The transition between the two lower levels b1 and b2 is dipole forbidden and the transition from the upper level a to any of the lower levels b1 and b2 is allowed. The frequencies of the transitions a→b1 and a→b2, coincide with those of the modes 1 and 2 of the microwave cavity so that the atom and the fields interact resonantly. We also neglect

FIG. 1. The scheme of the two-mode micromaser and the energy-level diagram for the analysis.