Origin and restoration of missing interference in emission in a laser-driven V system

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(Received 20 January 1998)

We present physical reasoning for the missing interference [Zhu, Narducci, and Scully, Phys. Rev. A 52, 4791 (1995)] in emission in a laser-driven V system. We demonstrate how the interference effects can be restored by considering an additional channel of spontaneous emission. Analytical results are given to identify the various pathways contributing to this interference. The interference terms show up in the form of dispersive contributions to the line shape. [S1050-2947(98)05607-8]

PACS number(s): 42.50.Ct, 42.50.Lc

In the past few years quantum interference among different transition pathways has become a very important tool in controlling the optical properties of matter. This includes not only the linear but also nonlinear optical properties such as various macroscopic linear and nonlinear susceptibilities [1–3]. Considerable literature exists on the understanding of interferences in the absorption and gain spectra [4,5]. For example, in a recent publication [4(b)] the origin of quantum interferences in probe absorption in various level schemes (Λ, V, Ζ) was analyzed. The interferences were found to be constructive or destructive depending on the level scheme. It was also discussed how the nature of interferences could be changed by changing different relaxation parameters. Since in a pumped system one does not necessarily have reciprocity [6] between emission and absorption, it becomes important to analyze the effects of relaxation parameters on interferences in the emission spectrum. Quantum interference has also been shown to be very important in the context of spontaneous emission [7] from, say, two close-lying states. The interference arises as the two pathways are created due to emission into a common vacuum of the electromagnetic field. More generally, if two or more close-lying states interact with a single bath (responsible for dissipative behavior), then the interference more or less always occurs [6].

There are exceptions, however. Zhu et al. [8] considered a coherently driven V system with ground level [3] connected to two upper levels [1] and [2] by a dipole transition. They examined the spontaneous emission spectrum on the transition [1]→[3] when the transition [2]→[3] was coherently driven. The coherent drive mixes strongly the levels [2] and [3] leading to new dressed states |ψ±⟩. The level separation between |ψ+⟩ and |ψ−⟩ depends on the strength and detuning of the coherent drive. They showed that the spectrum of spontaneous emission consists of two independent Lorentzians, i.e., there is no interference between two possible channels of emission, viz., [1]→|ψ+⟩ and [1]→|ψ−⟩. In quantum mechanics two transition amplitudes always interfere unless they are out of phase, thus the nonexistence of the quantum interference is surprising despite two apparent paths for emission to the state [3]. We would like to understand why there is no interference and how the two paths can be made to interfere [9]. We demonstrate that the interference can arise if we include spontaneous decay of the state [2] to [3]. Thus interference can appear from the opening up of a new pathway due to spontaneous emission on the transition [2]→[3].

We note that the emission spectra for coherently driven multilevel systems have been calculated extensively [10] and these spectra have been analyzed over a very wide range of parameters. However, most of these studies concentrated on the behavior of resonances in the spectra and were not concerned with quantum interferences, which are being discussed now [11]. Thus we analyze the spectra from the point of view of quantum interferences. We analyze the conditions under which interferences occur. We also note that the traditional secular approximation will miss such interferences and a suitable pumping mechanism with the levels of interest can restore the interferences.

The system under consideration is schematically shown in Fig. 1. The coherent driving field $\vec{E}_2 = e^{i\nu t} + c.c.$ with Rabi frequency $2G_2 = 2\hbar \gamma_3$, $\hbar / \hbar$ acts on the transition $|2\rangle \leftrightarrow |3\rangle$. We examine the spontaneous emission on the transition $|1\rangle \leftrightarrow |3\rangle$. Let $A_2$ be the detuning of the coherent drive: $A_2 = \omega_{23} - \omega_{11}$ with $\omega_{ij}$ representing the frequency of the transition $|i\rangle \leftrightarrow |j\rangle$. The level [1] can be pumped incoherently at the rate $2A(2A_0)$ from the state [3] (or externally). Let $2\gamma_2 = 2\gamma_1$ be the rates of emission from the level [2] ([1]) in the absence of the coherent drive. We work in the density matrix framework and we will discuss cases when either $A$ or $A_0 \neq 0$. Let $\omega_1$ be the frequency of the photon emitted on the transition $|1\rangle \leftrightarrow |3\rangle$ and let $A_1 = \omega_{13} - \omega_{11}$. A-

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FIG. 1. Schematic diagram of the laser-driven V system under consideration. We would consider the cases either with internal pumping ($A_0 = 0$) or with external pumping ($A = 0$).