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**TIME-DEPENDENT SPECTRUM  
OF COLLECTIVE RESONANCE  
FLUORESCENCE**

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## I. INTRODUCTION

In the last decade, the spectral and statistical properties in the resonance fluorescence of two-level atoms in the presence of a strong driving laser field have received a great deal of attention, both theoretical [1,2,6-22] and experimental [3-5]. Further understanding of the fluorescence dynamics for a single-atom case has been considered in the works by Eberly et al. [8,11], Renaud et al. [16], Courtens and Sröke [17] and Tak-San Ho et al. [13].

In this paper we investigate the dynamical evolution of the collective resonance fluorescence spectrum from  $N$  two-level atoms in the presence of strong and exact resonant driving laser field. In the secular approximation [18,19], the analytical formulas for a physical time-dependent spectrum are given. The influence of the transient spectral form on the parameters of the atomic system such as the number of atoms  $N$ , absolute value of the initial atomic population inversion  $|D|$ , atomic spontaneous transition rate  $\gamma$  and the width of the filter  $\Gamma$  is discussed. Essential differences of the transient spectral form from the steady state spectrum will be shown in this paper.

## II. THE BASIC EQUATIONS

We consider  $N$  two-level identical atoms of the Dicke model which interact with a strong monochromatic mode of the laser field at frequency  $\omega_L$  and with the vacuum of other modes in the context of collective resonance fluorescence [18-21].



In treating the external field classically and using the Born and Markov approximation describing the coupling of the system with the vacuum field, one finds a master equation for the reduced density matrix for the reduced atomic system (in the interaction representation) in the form [19]

$$\frac{\partial \rho}{\partial t} = -i\Omega [J_{12} + J_{21}, \rho] - \frac{\gamma}{2} (J_{21} J_{12} \rho - J_{12} \rho J_{21} + H.C.), \quad (1)$$

$$= L\rho,$$

where  $\gamma$  is the atomic spontaneous transition rate,  $\Omega$  is the resonant Rabi frequency. The operators  $J_{ij}$  ( $i, j = 1, 2$ ) are the usual collective atomic angular operators satisfying the well-known commutation relation

$$[J_{ij}, J_{i'j'}] = J_{ij'} \delta_{ji'} - J_{i'j} \delta_{ij'} \quad (2)$$

For simplicity, the laser frequency  $\omega_L$  is assumed to be exactly equal to the atomic transition frequency  $\omega_{21}$ .

Following the authors of the works [18, 23] we introduce the Schwinger representation for the angular momentum

$$J_{ij} = C_i^+ C_j \quad (i, j = 1, 2),$$

where  $C_i$ , and  $C_j^+$  obey the boson commutation relation

$$[C_i, C_j^+] = \delta_{ij}.$$

Further, we investigate only the case of an intense external field so that the Rabi frequency  $\Omega$  satisfies the relation

$$\Omega \gg \gamma. \quad (3)$$

After performing the canonical (dressing) transformation

$$C_1 = \frac{1}{\sqrt{2}} Q_1 + \frac{1}{\sqrt{2}} Q_2, \quad (4)$$

$$C_2 = -\frac{1}{\sqrt{2}} Q_1 + \frac{1}{\sqrt{2}} Q_2,$$

one finds that the Liouville operator  $L$  appearing in equation (1) splits into two components  $L_0$  and  $L_1$ . The component  $L_0$  is slowly varying in time whereas  $L_1$  contains rapidly oscillating terms at frequencies  $2\Omega$  and  $4\Omega$ . For the case when the relation (2) is fulfilled, one can make the secular approximation, i.e., to retain only the slowly varying part [18, 19] and reduce the master equation (1) to the form

$$\frac{\partial \tilde{\rho}}{\partial t} = -i\Omega [R_3, \tilde{\rho}] + \frac{\gamma}{8} (2R_3 \tilde{\rho} R_3 - R_3^2 \tilde{\rho} - \tilde{\rho} R_3^2) + \frac{\gamma}{8} (2R_{12} \tilde{\rho} R_{21} - R_{21} R_{12} \tilde{\rho} - \tilde{\rho} R_{21} R_{12}) + \frac{\gamma}{8} (2R_{21} \tilde{\rho} R_{12} - R_{12} R_{21} \tilde{\rho} - \tilde{\rho} R_{12} R_{21}), \quad (5)$$

where  $\tilde{\rho} = U\rho U^+$  with  $U$  is the unitary operator representing the canonical transformation (4);  $R_3 = R_{22} - R_{11}$ ;

$R_{ij} = Q_i^+ Q_j$  ( $i, j = 1, 2$ ) are the collective angular operators of the dressed atoms. The operators  $Q_i$  and  $Q_j^+$  satisfy the boson commutation

$$[Q_i, Q_j^+] = \delta_{ij}, \quad (6)$$

so that

$$[R_{ij}, R_{i'j'}] = R_{ij'} \delta_{i'j} - R_{i'j} \delta_{ij'} \quad (7)$$

The equation of motion for the expectation value of an arbitrary (fixed) atomic operator  $B$  follows from equation (5)

$$\langle \dot{B} \rangle_t = i\Omega \langle [B, R_3] \rangle_t + \frac{\gamma}{8} \left\{ \langle [R_3, B] R_3 \rangle_t + \langle R_3 [B, R_3] \rangle_t \right\} + \frac{\gamma}{8} \left\{ \langle [R_{21}, B] R_{12} \rangle_t + \langle R_{21} [B, R_{12}] \rangle_t + \langle [R_{12}, B] R_{21} \rangle_t + \langle R_{12} [B, R_{21}] \rangle_t \right\}, \quad (8)$$

where

$$\langle B \rangle_t \equiv \langle B(t) \rangle = S\rho(\rho(t)B) \quad (9)$$

In particular, we have

$$\begin{aligned} \frac{d}{dt} \langle R_{21} \rangle_t &= 2i\Omega \langle R_{21} \rangle_t - \frac{3}{4} \gamma \langle R_{21} \rangle_t \\ &= \frac{d}{dt} \langle R_{12} \rangle_t^* \end{aligned} \quad (10)$$

$$\frac{d}{dt} \langle R_3 \rangle_t = -\frac{\gamma}{2} \langle R_3 \rangle_t \quad (11)$$

By using the quantum regression theorem [24,25] one finds the equations of motion for the two-time correlation functions. In particular, we obtain equations of motion for the two-time correlation functions

$$\begin{aligned} \langle R_3(t+\tau) R_3(t) \rangle; \\ \langle R_{21}(t+\tau) R_{12}(t) \rangle \\ \text{and} \quad \langle R_{12}(t+\tau) R_{21}(t) \rangle \end{aligned}$$

in the following form:

$$\frac{d}{d\tau} \langle R_3(t+\tau) R_3(t) \rangle = -\frac{\gamma}{2} \langle R_3^2 \rangle_t \quad (12)$$

$$\frac{d}{d\tau} \langle R_{21}(t+\tau) R_{12}(t) \rangle = (2i\Omega - \frac{3}{4}\gamma) \langle R_{21} R_{12} \rangle_t \quad (13)$$

$$\frac{d}{d\tau} \langle R_{12}(t+\tau) R_{21}(t) \rangle = (-2i\Omega - \frac{3}{4}\gamma) \langle R_{12} R_{21} \rangle_t \quad (14)$$

Equations (12-14) give the solutions

$$\langle R_3(t+\tau) R_3(t) \rangle = e^{-\frac{\gamma}{2}\tau} \langle R_3^2 \rangle_t \quad (15)$$

$$\langle R_{21}(t+\tau) R_{12}(t) \rangle = e^{(2i\Omega - \frac{3}{4}\gamma)\tau} \langle R_{21} R_{12} \rangle_t \quad (16)$$

$$\langle R_{12}(t+\tau) R_{21}(t) \rangle = e^{(-2i\Omega - \frac{3}{4}\gamma)\tau} \langle R_{12} R_{21} \rangle_t \quad (17)$$

The equations of motion for the expectation values  $\langle R_3^2 \rangle_t$ ,  $\langle R_{21} R_{12} \rangle_t$  and  $\langle R_{12} R_{21} \rangle_t$  can be derived from equation (8) and commutation relation (7) and have the exact solutions in the following form:

$$\langle R_3^2 \rangle_t = \langle R_3^2 \rangle_s + e^{-\frac{3}{2}\gamma t} (\langle R_3^2 \rangle_0 - \langle R_3^2 \rangle_s) \quad (18)$$

$$\begin{aligned} \langle R_{21} R_{12} \rangle_t &= \langle R_{21} R_{12} \rangle_s + e^{-\frac{3}{2}\gamma t} [\langle R_{21} R_{12} \rangle_0 \\ &- \langle R_{21} R_{12} \rangle_s + \frac{3}{4} \langle R_3 \rangle_0 (e^{\gamma t} - 1)] \end{aligned} \quad (19)$$

$$\begin{aligned} \langle R_{12} R_{21} \rangle_t &= \langle R_{12} R_{21} \rangle_s + e^{-\frac{3}{2}\gamma t} [\langle R_{12} R_{21} \rangle_0 \\ &- \langle R_{12} R_{21} \rangle_s - \frac{1}{4} \langle R_3 \rangle_0 (e^{\gamma t} - 1)] \end{aligned} \quad (20)$$

where

$$\langle R_3^2 \rangle_s = \langle R_3^2 \rangle_t \rightarrow \infty = \frac{1}{3} (N^2 + 2N) \quad (21)$$

$$\langle R_{21} R_{12} \rangle_s = \langle R_{12} R_{21} \rangle_s = \frac{1}{6} (N^2 + 2N) \quad (22)$$

$\langle \dots \rangle_0$  denotes the expectation value over the initial state of the atomic system. In the case when the atoms are initially in the symmetric Dicke state

$$\rho_0 = |n_1, n_2\rangle \langle n_1, n_2| \quad (23)$$

where

$$\begin{aligned} J_{22} |n_1, n_2\rangle &= n_2 |n_1, n_2\rangle \\ J_{11} |n_1, n_2\rangle &= n_1 |n_1, n_2\rangle \end{aligned}$$

one can find

$$\langle R_3 \rangle_0 = 0 \quad (24)$$

$$\langle R_3^2 \rangle_0 = \frac{1}{2} (N^2 + 2N - D^2) \quad (25)$$

$$\langle R_{21} R_{12} \rangle_0 = \langle R_{12} R_{21} \rangle_0 = \frac{1}{8} (N^2 + 2N + D^2) \quad (26)$$

where

$$D = n_2 - n_1$$

### III. TIME-DEPENDENT FLUORESCENCE SPECTRUM

Following Eberly et al. [22] the time dependent physical

spectrum of the fluorescence field has the explicit form:

$$S(t, \omega_f, \Gamma) = 2\Gamma \operatorname{Re} \int_0^t dt_2 e^{-\Gamma(t-t_2)} \int_0^{t-t_2} d\tau e^{(\frac{\Gamma}{2} - i\Delta)\tau} \langle J_{21}(t_2 + \tau) J_{12}(t_2) \rangle, \quad (27)$$

where  $\Delta = \omega_f - \omega_L$  with  $\omega_f$  is the center frequency of the filter;  $\Gamma$  is the width of the filter;  $t$  is the time at which the spectrum is evaluated.

For the case of intense external field the members in spectrum (27), which are proportional to  $\Omega^{-1}$ , are ignored and the spectrum (27) reduces to

$$S(t, \omega_f, \Gamma) = \Gamma/2 \operatorname{Re} \int_0^t dt_2 e^{-\Gamma(t-t_2)} \int_0^{t-t_2} d\tau e^{(\frac{\Gamma}{2} - i\Delta)\tau} \left\{ \langle R_3(t_2 + \tau) R_3(t_2) \rangle + \langle R_{21}(t_2 + \tau) R_{12}(t_2) \rangle + \langle R_{12}(t_2 + \tau) R_{21}(t_2) \rangle \right\} \quad (28)$$

For the case when the atoms are initially in the Dicke state (23), using relations (17)-(15) and (24)-(26) one can write the spectrum (28) in the form

$$S(t, \omega_f, \Gamma) = S_0(t, \omega_f, \Gamma) + S_1(t, \omega_f, \Gamma) + S_{-1}(t, \omega_f, \Gamma), \quad (29)$$

where

$$S_0(t, \omega_f, \Gamma) = \operatorname{Re} \left\{ \langle R_3^2 \rangle_0 \cdot \Gamma \left[ \frac{\exp(-\frac{3}{2}\Gamma t)}{(\Gamma - \frac{3}{2}\gamma)(\Gamma - 2\gamma + 2i\Delta)} - \frac{2 \exp[-\frac{1}{2}(\Gamma + \gamma + 2i\Delta)t]}{(\Gamma - 2\gamma + 2i\Delta)(\Gamma - \gamma - 2i\Delta)} \right] + \langle R_3^2 \rangle_3 \left[ \frac{1}{\Gamma + \gamma + 2i\Delta} - \frac{\Gamma \exp(-\frac{3}{2}\Gamma t)}{(\Gamma - \frac{3}{2}\gamma)(\Gamma - 2\gamma + 2i\Delta)} \right] - \frac{\frac{3}{2}\gamma \exp(-\Gamma t)}{(\Gamma - \frac{3}{2}\gamma)(\Gamma - \gamma - 2i\Delta)} + \frac{6\gamma \Gamma \exp[-\frac{1}{2}(\Gamma + \gamma + 2i\Delta)t]}{(\Gamma - 2\gamma + 2i\Delta)(\Gamma + \gamma + 2i\Delta)(\Gamma - \gamma - 2i\Delta)} \right\} \quad (30)$$

$$S_1(t, \omega_f, \Gamma) = \operatorname{Re} \left\{ \langle R_{21} R_{12} \rangle_0 \cdot \Gamma \left[ \frac{\exp(-\frac{3}{2}\Gamma t)}{(\Gamma - \frac{3}{2}\gamma)(\Gamma - \frac{3}{2}\gamma + 2i\Delta_1)} \right] \right\}$$

$$+ \frac{\exp(-\Gamma t)}{(\Gamma - \frac{3}{2}\gamma)(\Gamma - \frac{3}{2}\gamma - 2i\Delta_1)} - \frac{2 \exp[-\frac{1}{2}(\Gamma + \frac{3}{2}\gamma + 2i\Delta_1)t]}{(\Gamma - \frac{3}{2}\gamma)^2 + 4\Delta_1^2} \left. \right\} + \langle R_{21} R_{12} \rangle_3 \left[ \frac{1}{\Gamma + \frac{3}{2}\gamma + 2i\Delta_1} - \frac{\Gamma \exp(-\frac{3}{2}\Gamma t)}{(\Gamma - \frac{3}{2}\gamma)(\Gamma - \frac{3}{2}\gamma + 2i\Delta_1)} - \frac{\frac{3}{2}\gamma \exp(-\Gamma t)}{(\Gamma - \frac{3}{2}\gamma)(\Gamma - \frac{3}{2}\gamma - 2i\Delta_1)} + \frac{6\gamma \Gamma \exp[-\frac{1}{2}(\Gamma + \frac{3}{2}\gamma + 2i\Delta_1)t]}{[(\Gamma - \frac{3}{2}\gamma)^2 + 4\Delta_1^2](\Gamma + \frac{3}{2}\gamma + 2i\Delta_1)} \right] \quad (31)$$

$$S_{-1}(t, \omega_f, \Gamma) = S_1(\Delta_1 \rightarrow -\Delta_1) \quad (32)$$

$$\Delta = \omega_f - \omega_L; \quad \Delta_1 = \omega_f - \omega_L - 2\Omega$$

$$\Delta_{-1} = \omega_f - \omega_L + 2\Omega.$$

The expectation values  $\langle R_3^2 \rangle_3$ ,  $\langle R_{21} R_{12} \rangle_3$  and  $\langle R_3^2 \rangle_0$ ,  $\langle R_{21} R_{12} \rangle_0$  in eqs. (36), (37) can be found in eqs. (21), (22) and (25), (26), respectively.

Expressions (29)-(32) describe the dynamic evolution of the collective fluorescence spectrum. Analogously to the one-atom fluorescence [16] the spectrum (29) (in the strong external field case) contains three spectrum components centered at frequencies  $\omega_f = \omega_L - 2\Omega$ ,  $\omega_L$  and  $\omega_L + 2\Omega$ , respectively. For the stationary limit  $t \rightarrow \infty$  the spectrum (29) reduces to [19]

$$S(\infty, \omega_f, \Gamma) = \frac{1}{3} (N^2 + 2N) \left\{ \frac{\frac{\gamma}{2} + \frac{\Gamma}{2}}{\left(\frac{\gamma}{2} + \frac{\Gamma}{2}\right)^2 + (\omega_f - \omega_L)^2} + \frac{\frac{\Gamma}{2} + \frac{3}{4}\gamma}{\left(\frac{\Gamma}{2} + \frac{3}{4}\gamma\right)^2 + (\omega_f - \omega_L - 2\Omega)^2} + \frac{\frac{\Gamma}{2} + \frac{3}{4}\gamma}{\left(\frac{\Gamma}{2} + \frac{3}{4}\gamma\right)^2 + (\omega_f - \omega_L + 2\Omega)^2} \right\} \quad (33)$$

The collective steady-state spectrum (33) has the same form as for the single-atom case but all the weighting factors are proportional to  $N^2$ . The relations between the peak intensities of the spectrum components (i.e. the quantities  $I_0 = S_0(\Delta=0)$ ;  $I_1 = S_1(\Delta_1=0)$ ;  $I_{-1} = S_{-1}(\Delta_{-1}=0)$ ) take the form

$$I_{S_0} : I_{S_{-1}} : I_{S_{+1}} = 2:1:1 \quad \text{for } \Gamma \gg \delta,$$

$$I_{S_0} : I_{S_{-1}} : I_{S_{+1}} = 3:1:1 \quad \text{for } \Gamma \ll \delta. \quad (34)$$

For a short time limit  $\Gamma t$ ,  $\Gamma t \ll 1$  the peak intensities of the three spectrum components  $S_0$ ,  $S_{-1}$  and  $S_{+1}$  are

$$I_{S_0} = \frac{1}{4} \langle R_3^2 \rangle_0 \Gamma t^2, \quad (35)$$

$$I_{S_{-1}} = I_{S_{+1}} = \frac{1}{4} \langle R_{21} R_{12} \rangle_0 \Gamma t^2. \quad (36)$$

For the case when all the atoms are initially in the ground state (or excited state) i.e.  $D = n_2 - n_1 = -N$  ( $+N$ ), one shows from equations (25) and (26) that

$$\langle R_3^2 \rangle_0 = N, \quad (37)$$

$$\langle R_{21} R_{12} \rangle_0 = \frac{1}{4} (N^2 + N), \quad (38)$$

thus the peak intensity (35) of the central component  $S_0$  is proportional to  $N$  while the peak intensities (36) of the sidebands  $S_{\pm 1}$  are proportional to  $N^2$ . For the case when the atomic population inversion  $D = 0$ , one finds from eqs.(25) and (26):

$$\langle R_3^2 \rangle_0 = \frac{1}{2} (N^2 + 2N) = 4 \langle R_{21} R_{12} \rangle_0 = 4 \langle R_{12} R_{21} \rangle_0,$$

thus in this case all the three spectrum components have the peak intensities (35),(36) being proportional to  $N^2$  and relations between the peak intensities take the form

$$I_{S_0} : I_{S_{-1}} : I_{S_{+1}} = 4:1:1. \quad (39)$$

In other words, the form of the fluorescence spectrum (i.e. the relations between the peak intensities) in the initial period of

time is quite different from the steady-state fluorescence spectrum (33) and is strongly dependent on the number of atoms  $N$  and absolute value of the atomic population inversion  $|D|$ .

For the Rydberg atoms when  $\Gamma \gg \delta \approx 0$  the fluorescence spectrum (30)-(32) reduces to

$$S_0(t, \omega_f, \Gamma) = \langle R_3^2 \rangle_0 \text{Re} \left\{ \frac{e^{-\Gamma t} - 1}{\Gamma - 2i\Delta} + 2 \frac{1 - e^{-(\frac{\Gamma}{2} + i\Delta)t}}{\Gamma^2 + 4\Delta^2} \right\}, \quad (40)$$

$$S_{\pm 1}(t, \omega_f, \Gamma) = \langle R_{21} R_{12} \rangle_0 \text{Re} \left\{ \frac{e^{-\Gamma t} - 1}{\Gamma - 2i\Delta_{\pm 1}} + 2 \frac{1 - e^{-(\frac{\Gamma}{2} + i\Delta_{\pm 1})t}}{\Gamma^2 + 4\Delta_{\pm 1}^2} \right\} \quad (41)$$

$$S_{-1}(t, \omega_f, \Gamma) = S_1(\Delta_1 \rightarrow \Delta_{-1}) \quad (42)$$

The spectrum (40)-(42) is in agreement with our previous work [21] concerning the collective resonance fluorescence from  $N$  atoms in the ideal cavity where for the case of  $|D| \sim N$  only the sidebands exhibit superradiant behaviour ( $\sim N^2$ ) while the intensity of the central component is proportional to  $N$ .

For the other limited case  $\delta \gg \Gamma$ , ignoring the terms which are proportional to  $\frac{\Gamma}{\delta}$  in the spectrum (29), one obtains

$$S(t, \omega_f, \Gamma) = \frac{1}{3} (N^2 + 2N) (1 - e^{-\Gamma t}) \left\{ \frac{\delta/2}{(\delta/2)^2 + \Delta^2} + \frac{1}{2} \frac{3/4 \Gamma}{9/16 \delta^2 + \Delta_1^2} + \frac{1}{2} \frac{3/4 \delta}{9/16 \delta^2 + \Delta_2^2} \right\} \quad (43)$$

As for the steady state spectrum (33), in this case the transient spectrum (43) has the spectral form being independent of  $N$  and the weighting factors for all the three spectrum components are proportional to  $N^2$ .

In the single-atom case one finds from eqs. (21), (22) and (24), (25) that

$$\langle R_3^2 \rangle_s = \langle R_3^2 \rangle_0 = 1$$

$$\langle R_{21} R_{12} \rangle_s = \langle R_{21} R_{12} \rangle_0 = \frac{1}{2}$$

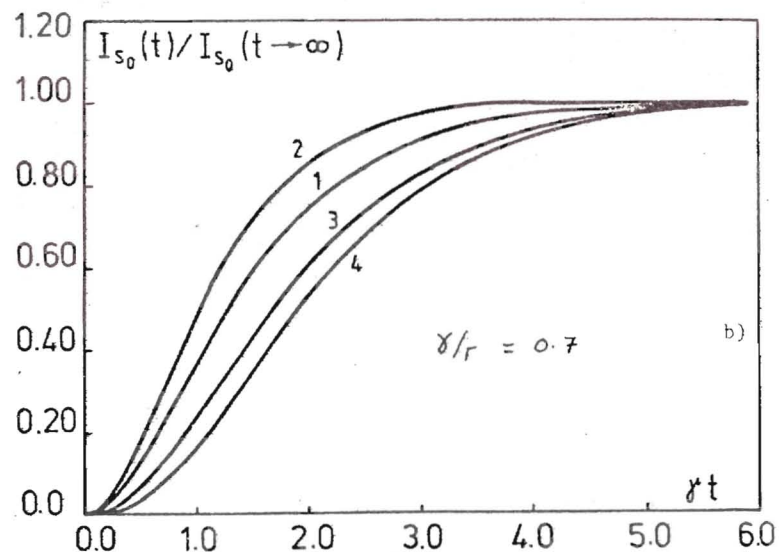
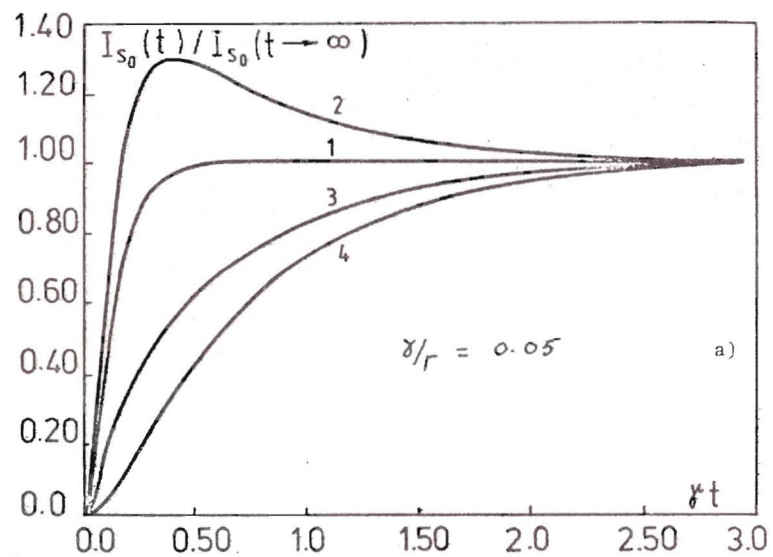


Fig. 1. Normalized peak intensity of the central component

$I_{S_0}(t)/I_{S_0}(t \rightarrow \infty)$  as a function of  $\gamma t$ . The curves 1-4 corresponding to the cases  $N = 1, D = \pm 1$ ;  $N = 6, D = 0$ ;  $N = 6, D = \pm 6$  and  $N = 80, D = \pm 80$ , respectively.

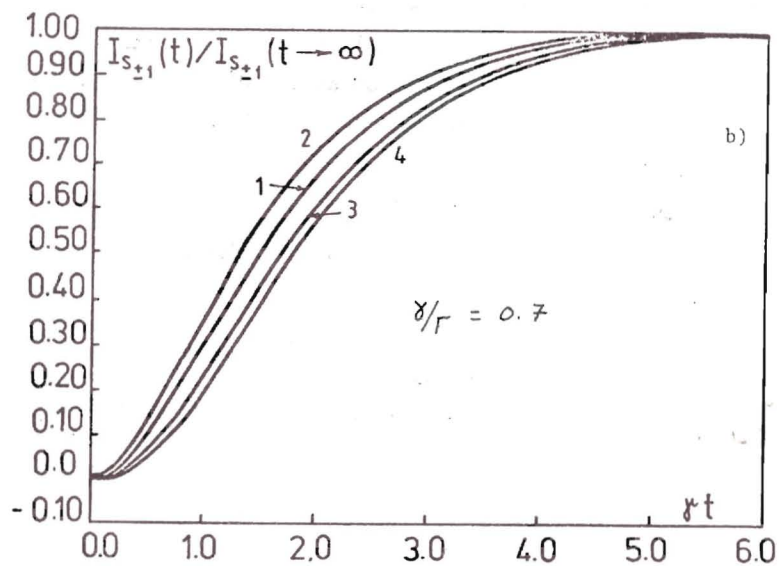
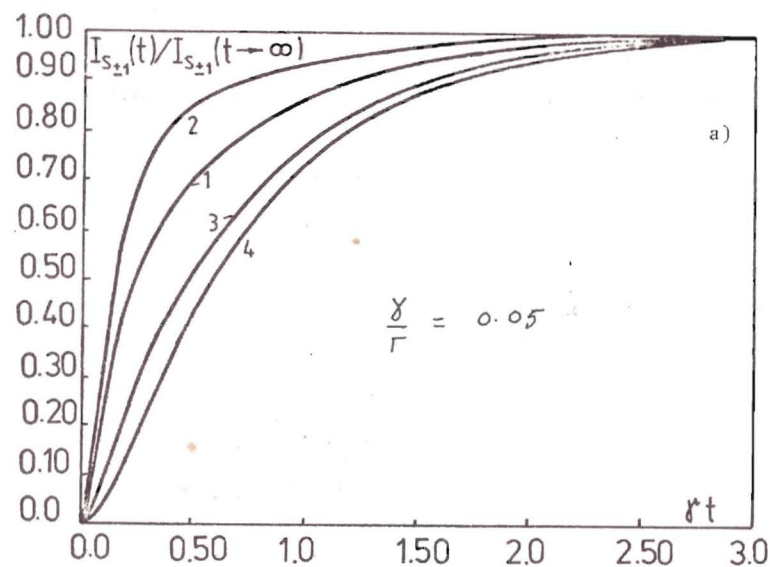


Fig. 2. Normalized peak intensity of the sidebands

$I_{S_{\pm 1}}(t)/I_{S_{\pm 1}}(t \rightarrow \infty)$  as a function of  $\gamma t$ . The curves 1-4 corresponding to the cases  $N = 1, D = \pm 1$ ;  $N = 6, D = 0$ ;  $N = 6, D = \pm 6$  and  $N = 80, D = \pm 80$ , respectively.

and spectrum (29) reduces to the time-dependent spectrum of one atom in the works [8, 16-17] (in the secular approximation).

For the general case the dependence of the transient peak intensities of the spectrum components  $S_0$ ,  $S_{\pm 1}$  on the atomic parameters  $N$ ,  $|D|$ ,  $\gamma$  and on the width of the filter  $\Gamma$  is shown in figs. (1), (2) where the normalized peak intensities of the central component, i.e. the quantity

$$I_{S_0}(t, \Delta=0, \Gamma) / I_{S_0}(\infty, \Delta=0, \Gamma) \quad (\text{see fig. 1}),$$

and of the sidebands, i.e. the quantities

$$I_{S_{\pm 1}}(t, \Delta_{\pm 1}=0, \Gamma) / I_{S_{\pm 1}}(\infty, \Delta_{\pm 1}=0, \Gamma) \quad (\text{see fig. 2}),$$

are plotted as functions of the time  $\tau = \gamma t$  for various values of the parameters  $N$ ,  $D$  and  $\gamma/\Gamma$ . In contrast with the steady-state spectrum (33) where the spectrum form is independent of the number of atoms, in the general case the transient spectrum form is dependent on the number of atoms  $N$  except the case when the initial atomic population inversion  $D = 0$  (see the curves (4) in figs. 1, 2).

As is seen from figs. 1, 2 and relations (31), (32), for the case when the atoms are initially in the symmetric Dicke state (23), the spectrum is symmetric. However, we note that in the case when atoms are initially in the coherent state so that  $\langle R_3 \rangle_0 \neq 0$ , one can show from eqs. (19), (20) that  $\langle R_{21} R_{12} \rangle_t \neq \langle R_{12} R_{21} \rangle_t$  and consequently the fluorescence spectrum becomes unsymmetric.

#### IV. CONCLUSIONS

We have considered the problem of physical time-dependent spectrum of the collective resonance fluorescence from  $N$  two-level atoms in the presence of the strong and exact resonant

laser driving field. By using the secular approximation the analytical formulas for the transient spectrum are given. In contrast with the steady-state spectrum, the form of the transient spectrum is strongly dependent on the number of atoms  $N$ , the absolute value of the initial atomic population  $|D|$ , spontaneous transition rate  $\gamma$  and the width of the filter  $\Gamma$ . For the initial period of the time (short time limit) and  $|D| \approx N$  only two sidebands exhibit the superradiance behaviour ( $\sim N^2$ ) while the intensity of the central spectrum component is proportional only to  $N$ .

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