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An atom near a phase conjugator (PC) is theoretically seen to behave quite differently than an atom in empty space or an atom near an ordinary (linear) surface. With two laser beams which pump the nonlinear crystal (PC), it is found that an atom in its ground state can fluoresce if it is sufficiently close to a PC. The possible mechanism involves the atomic transition dipole polarizing the PC, which then spontaneously emits a photon focused on the atom. With stimulated absorption and subsequent spontaneous emission, the net effect is that the atom remains in its ground state.

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EXTRAORDINARY BEHAVIOR OF ATOMS NEAR A PHASE CONJUGATOR

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An atom near a phase conjugator (PC) behaves quite differently than an atom in empty space, or an atom in the vicinity of an ordinary (linear) surface. A spherical diverging wave, which is emitted by the atomic dipole $\underset{\sim}{\mu}$, is reflected by the PC as a converging wave, and exactly focused on the emitting atom. This gives rise to a high probability for reabsorption of the photon that was just emitted. It can be anticipated that this mechanism leads to a strong enhancement of the effective lifetime of an excited state. We have calculated the spatial intensity distribution of the fluorescence, which is emitted in the half space to the 'left' of the PC (Fig. 1), and the total emitted power

$$P(t) = 2\epsilon_o c r^2 \int d\Omega \, \langle \underset{\sim}{E}^{(-)}(\underset{\sim}{r},t) \cdot \underset{\sim}{E}^{(+)}(\underset{\sim}{r},t) \rangle \qquad (1)$$

in the radiation zone. The angle brackets denote a quantum average, and $\underset{\sim}{E}^{(+)}(\underset{\sim}{r},t)$ is the positive-frequency part of the electric field operator in the Heisenberg picture. This $\underset{\sim}{E}^{(+)}$ is the solution of Maxwell's equations for this configuration, and it includes both the emitted field by the dipole and the field which is reflected by the PC. It is assumed that the PC is of the four-wave mixing type.

For a degenerate two-level atom we find the general expression

$$P(t) = \frac{\omega_o^4}{6\pi\epsilon_o c^3} \mathrm{Tr}\rho(t-r/c)\left(\underset{\sim}{\mu}^{(-)} \cdot \underset{\sim}{\mu}^{(+)} + c_{\parallel} \underset{\sim}{\mu}_{\parallel}^{(+)} \cdot \underset{\sim}{\mu}_{\parallel}^{(-)} + c_{\perp} \underset{\sim}{\mu}_{\perp}^{(+)} \cdot \underset{\sim}{\mu}_{\perp}^{(-)}\right) \quad , \qquad (2)$$

where (+) indicates the lowering part of the dipole operator (Schrödinger picture). Here, $\rho(t)$ is the density operator of the atom only, and ω_o is the atomic transition frequency. The two c-coefficients are found to be [1]

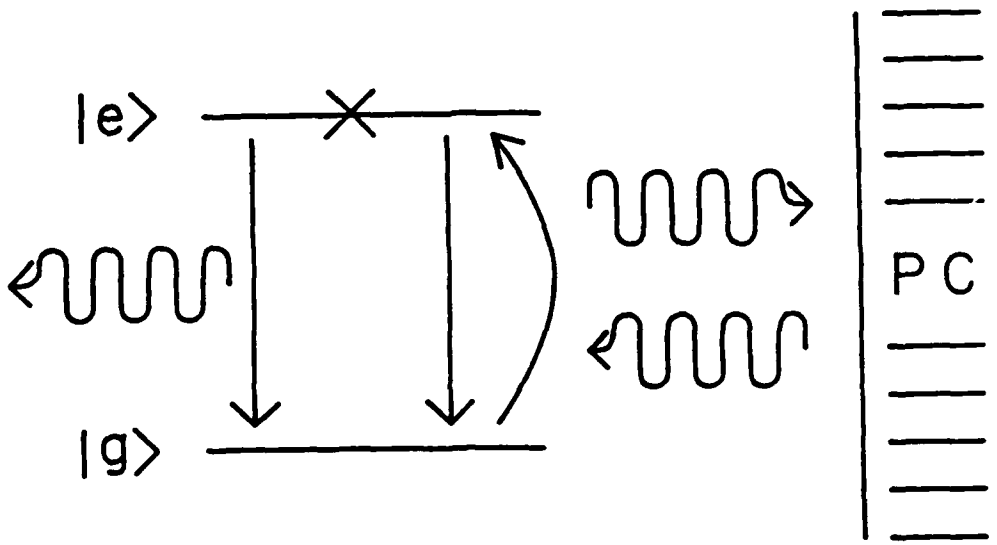

Fig. 1. Illustration of the possible mechanisms which give rise to the first term on the right-hand side of Eq. (4). A photon emitted to the left can be detected, but a photon that hits the PC never reaches the detector. This is either because this photon is absorbed by the medium, or it is absorbed by the atom after reflection. The figure depicts the second mechanism.

$$c_{\parallel} = \frac{3}{4}\int_0^1 du\ (1+u^2)\,|R(\omega_o,u)|^2 \quad , \quad c_{\perp} = \frac{3}{2}\int_0^1 du\ (1-u^2)\,|R(\omega_o,u)|^2 \quad , \tag{3}$$

where R is the Fresnel coefficient for reflection of a plane wave with the cosine of the angle of incidence on the surface of the PC equal to u. These coefficients also depend on the atomic level separation ω_o, in general. In the case that the dependence of the Fresnel coefficients on the angle of incidence can be neglected, both c-coefficients reduce to $|R|^2$.

Expression (2) can be simplified considerably if we assume that the atom has only two states, and that R varies only slightly with the angle of incidence. Then Eq. (2) reduces to

$$P(t) = \frac{1}{2} A\hbar\omega_o [n_e(t-r/c) + |R|^2 n_g(t-r/c)] \quad , \tag{4}$$

with A as the Einstein coefficient for spontaneous decay in empty space, and n_e and n_g as the populations of the excited and ground state, respectively. Nothing has been assumed about the time dependence of these populations, and so Eq. (4) holds also when the atom is not in its steady state.

Result (4) has two remarkable features. First, we notice that the first term, which is proportional to n_e, is just one half times the emission rate of an atom in empty space. This implies that the photons which are emitted towards the PC, and subsequently reflected (Fig. 1), are reabsorbed completely. No reflected photon passes the atom. We would like to emphasize, however, that this is only one of the tenable interpretations of the first term in Eq. (4). It is also possible that the PC absorbs the photon which is incident on its surface completely, and without reflection. This process would leave the atom in its ground state, rather than in its excited state, after occurrence of this process. Another possibility would be that both processes can happen.

Secondly, we see that P(t) has a term proportional to the population of the ground state. From this we conclude that an atom in its ground state can fluoresce, if it is sufficiently close to a PC. The possible mechanism is illustrated in Fig. 2. The presence of the atomic dipole moment polarizes the PC, which then spontaneously emits a photon, focused on the atom. Stimulated absorption and subsequent spontaneous emission gives rise to an observable photon at the left. The net effect is that the atom remains in its ground state. The required energy for this process is of course provided by the two laser beams which pump the nonlinear crystal.

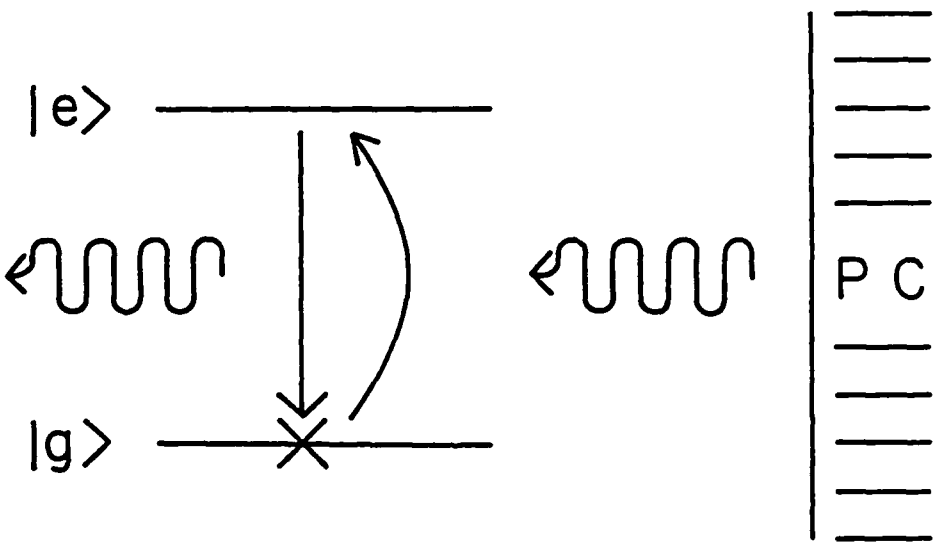

Fig. 2. As predicted by Eq. (4), an atom in its ground state can effectively emit a photon. Due to energy conservation this photon must first be extracted from the PC. The polarized PC spontaneously emits a focused photon, which is absorbed by the atom. Spontaneous excitation and subsequent decay produce a detectable photon at the left. After the process, the atom is again in its ground state.

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[1] H. F. Arnoldus and T. F. George, Opt. Lett. (1989), submitted.

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