NEGATIVE RESONANCE ABSORPTION OF LIGHT IN A STABLE MEDIUM

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It is shown that negative absorption of light in a medium containing quantum emitters of two types with equidistant transitions may be of a threshold nature. Moreover, the medium is stable with respect to the photon background of spontaneous origin.

NEGATIVE resonance absorption of light [1-6] is observed in a medium in the case when induced emission in it predominates over the process of resonance absorption and the dissipation of light energy, i.e., when $\gamma_n(\nu) \equiv -\alpha u + B_n(\nu)h\nu(n_2 - n_1) > 0$, where u is the velocity of light in the medium, α is the absorption coefficient characterizing the dissipation, ν is the frequency of the light, n_2 and n_1 are the volume densities of the quantum emitters in the upper and lower levels of the transition $2 \longleftrightarrow 1$ of energy $h\nu_0$ and characterized by the Einstein coefficient of induced emission $B_n(\nu)$. When this inequality is satisfied the phenomenon of negative absorption occurs for arbitrarily low densities of the photon field, including the case of the background level due to the spontaneous emission of photons in the corresponding modes of the medium. In this sense a medium characterized by $\gamma_n(\nu) > 0$ may be said to be unstable.

The object of the present article is to draw attention to the fact that negative absorption of light can under certain conditions be observed also in a medium which is stable in its initial state, and that the capacity for negative absorption will manifest itself only if the number of photons N per unit cross sectional area of the light beam exceeds a certain threshold value N_{th}, i.e., that

$$\gamma(\nu) \lesseqgtr 0, \quad \text{if} \quad N \lesseqgtr N_{th}. \tag{1}$$

Consider a one dimensional medium containing quantum emitters of two different types (n) and (m) with equidistant transitions $2 \longleftrightarrow 1$ which interact only via the common radiation field. In this case we have

$$\gamma_{nm}(\nu) = -\alpha u + B_n(\nu)h\nu(n_2 - n_1) + B_m(\nu)h\nu(m_2 - m_1) \tag{2}$$

where the coefficient $B_m(\nu)$ and the densities m_2 and m_1 refer to emitters of type (m).

The possibility of a change in the nature of absorption, including the case of a change in the sign of $\gamma(\nu)$ in accordance with condition (1), is based on the fact that the inducing action of the light propagating through the medium tends to equalize the populations of levels 2 and 1 of emitters of both types, i.e., to reduce the absolute value of the population differences $(n_2 - n_1)$ and $(m_2 - m_1)$ appearing in (2). Moreover, the nature of the variation of $\gamma_{nm}(\nu)$ is determined by the relationship between the coefficients B_n and B_m and the initial values of the excess populations $(n_2 - n_1)_0$ and $(m_2 - m_1)_0$.

For example, we assume that in the initial state the medium is stable, i.e., $[\gamma_{nm}(\nu)]_0 < 0$, with $(m_2 - m_1)_0 < 0$, while the action of constant pumping maintains the relationship $(n_2 - n_1)_0 > 0$. A quasimonochromatic light beam of frequency ν_0 causes the medium to leave this initial equilibrium state: the differences $|n_2 - n_1|$ and $|m_2 - m_1|$ decrease exponentially [4,6],1) so that

$$\gamma_{nm}(\nu_0, N) = -\alpha u + B_n h\nu_0 (n_2 - n_1)_0 \exp\left[-2\frac{B_n h\nu_0}{u}N\right] + B_m h\nu_0 (m_2 - m_1)_0 \exp\left[-2\frac{B_m h\nu_0}{u}N\right], \tag{3}$$

where B_n and B_m are evaluated for the central frequency ν_0.

Thus, $\gamma_{nm}(\nu_0, N)$ is a function of the number of photons N. If for a certain value $N = N_{th}$ it turns out that $\gamma_{nm}(\nu_0) = 0$ and at the same time $d\gamma_{nm}(\nu_0)/dN > 0$, then beams with the number of photons $N < N_{th}$ are damped out as a result of propagation in the medium, while for beams with numbers of photons $N > N_{th}$ the same medium which is stable in the original state acquires the capacity for negative absorption.

It can be shown that in order to realize such a

1)This is valid in the case of homogeneous broadening of the line corresponding to the transition $2 \leftrightarrow 1$ and under the condition that one can neglect the effect of pumping and of spontaneous decay on the populations of the levels compared to the inducing action of the resonance light.

medium with threshold properties it is necessary that its characteristics should satisfy the following relations

$$\frac{B_m}{B_n} > \left[1 - \frac{\alpha u}{B_n h\nu_0 (n_2 - n_1)_0}\right]^{-1}, \qquad (4)$$

$$\frac{B_n}{B_m}\left[1 - \frac{\alpha u}{B_n h\nu_0 (n_2 - n_1)_0}\right] < -\frac{(m_2 - m_1)_0}{(n_2 - n_1)_0} < \left(\frac{B_n}{B_m}\right)^2 \times \left[\frac{B_n h\nu_0 (n_2 - n_1)_0}{\alpha u}\left(1 - \frac{B_n}{B_m}\right)\right]^{(B_m/B_n)-1}. \qquad (5)$$

When these conditions are satisfied the threshold number of photons N_{th} is determined by (3) if we set its right hand side equal to zero.

It can also be shown that in the initial stable state of the medium there is constantly present in it an equilibrium background of spontaneous photons of density

$$S_{sp} = f\int_0^\infty [-\gamma_{nm}(\nu)]_0^{-1}\left[n_{20}\frac{F_n(\nu)}{\tau_n} + m_{20}\frac{F_m(\nu)}{\tau_m}\right]d\nu, \quad (6)$$

where τ_n and τ_m are the lifetimes with respect to spontaneous radiative transitions $2 \to 1$ and $F_n(\nu)$ and $F_m(\nu)$ are the functions giving the line shapes for the same transitions for emitters of types (n) and (m) respectively, while the factor $f \ll 1$ picks out from the set of directions of spontaneous emission only those which are related to the modes of a one dimensional medium.

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