Optically induced parametric resonance

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Aleksandrov *et al.*[1] reported observation of parametric resonance excited by a radio frequency field $h_1 \cos\Omega t$ that oscillates along a constant field $\mathbf{H}_0$, in a system of atoms subjected simultaneously to the action of circularly polarized resonant light directed perpendicular to the field $\mathbf{H}_0$. Under these conditions, parametric resonance is revealed by modulation of the intensity of the light of frequency $n\Omega$ absorbed or scattered by the atomic system, the modulation depth increasing in resonant fashion if $k\Omega = \gamma H_0$, where γ is the gyromagnetic ratio of the atoms and n and k are integers. A characteristic feature of the parametric-resonance lines in the total absence of radio-frequency broadening and of radiative shifts when the field amplitude h_1 is increased. This phenomenon owes its name to the modulation of one of the "parameters" of the atomic system, namely the Zeeman splitting of the magnetic sublevels of the atom in the field $\mathbf{H}_0 + \mathrm{h}_1 \cos\Omega t$.

We have observed and investigated a type of resonance that can be called optically induced parametric resonance, since in this case the relaxation time of the atoms, which is also a "parameter" of the atomic system, is modulated by optical methods.

The atoms are placed in a constant magnetic field H_0, along which is directed a beam of unpolarized resonant light (beam II), the intensity of which is modulated in accordance with the law $I_2(t) = I_{20}(1 + \epsilon \sin\Omega t)$, where ϵ is the modulation depth. It must be emphasized that this beam does not produce orientation, and leads only to modulation of the optical relaxation time of the atoms. A circularly polarized light beam of constant intensity (beam I) is directed perpendicular to the field $\mathbf{H}_0$ and is used to register the signal.

On the whole, the evolution of the magnetization $\mathbf{M}$ of the atomic system can be described by the equation

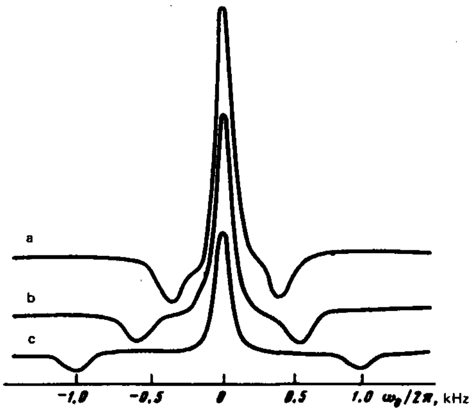

FIG. 1. Plots of resonance signals at a fixed modulation depth ϵ: a-$\Omega/2\pi=400$ Hz, b-$\Omega/2\pi=600$ Hz, c-$\Omega/2\pi=1000$ Hz.

$$\frac{d\mathbf{M}}{dt}=\frac{d\mathbf{M}^{(1)}}{dt}+\frac{d\mathbf{M}^{(2)}}{dt}+\frac{d\mathbf{M}^{(3)}}{dt}+\frac{d\mathbf{M}^{(4)}}{dt}, \tag{1}$$

where $d\mathbf{M}^1/dt=\gamma\mathbf{M}\times\mathbf{H}_0$ is the interaction with the magnetic field $\mathbf{H}_0=(0,0,H_0)$, γ is the gyromagnetic ratio, $d\mathbf{M}^{(2)}/dt=-\mathbf{M}/T_T$ is the thermal relaxation of the atoms (we assume for simplicity that $T_{T_1}=T_{T_2}=T_T$), $d\mathbf{M}^{(3)}/dt=(\mathbf{M}_0-\mathbf{M})/T_{p_1}$ is the interaction with beam I, T_{p_1} is the optical relaxation time connected with beam I, $M_0=(M_0,0,0)$ is the magnetization produced by beam I in the absence of magnetic fields; $d\mathbf{M}^{(4)}/dt=-\mathbf{M}/T_{p_2}$ is the atom relaxation due to beam II, and T_{p_2} is the optical relaxation time connected with beam II. Since $1/T_{p_2}\equiv\Gamma_{p_2}\sim I_2(t)$, it follows that

$$\Gamma_{p_2}=\Gamma_{o_2}(1+\epsilon\sin\Omega t). \tag{2}$$

By solving Eq. (1) we can easily obtain an expression for the xth component of the magnetization

$$M_x(t)=\frac{1}{T_{p_1}}M_o\,\mathrm{Re}\left\{\sum_{n=-\infty}^{\infty}\sum_{p=-\infty}^{\infty}\frac{I_n\left(\frac{\epsilon\Gamma_{o2}}{\Omega}\right)I_{n+p}\left(\frac{\epsilon\Gamma_{o2}}{\Omega}\right)}{\Gamma_o+i(\omega_o-n\Omega)}e^{ip\Omega t}\right\}, \tag{3}$$

where $\omega_0=\gamma H_0$, Γ_0 is the resonance line width at $\epsilon=0$, and I_n are modified Bessel functions of order n. Attention is called to the analogy between the obtained expression and the result describing parametric resonance.[1] The only difference is that here we use modified Bessel functions, the variation of which differs significantly from the behavior of ordinary Bessel functions of the first kind.

An analysis of (3) shows that the intensity of the transmitted light (beam I) should be modulated at frequencies $p\Omega$ and vary in resonant fashion near $\omega_0=n\Omega$, where n and p are integers. The signal strength increases with increasing modulation depth ϵ of the light, but the signal width and its position do not change.

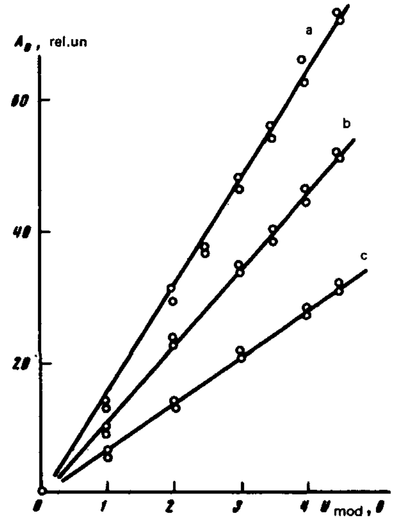

FIG. 2. Plots of the resonance-signal amplitudes against the modulating voltage: a-$\Omega/2\pi=400$ Hz, b-$\Omega/2\pi=600$ Hz, c-$\Omega/2\pi=100$ Hz.

The experiment was carried out in a system of Cs^{133} atoms in a cell with paraffin-coated walls. To exclude the influence of magnetic noise on the results of measurements in a weak magnetic field ($H_0\sim 3-5$ mOe was used in these experiments), the entire system was placed in a three-layer magnetic screen, in which the residual field was cancelled out along the three axes by a system of Helmholtz coils, accurate to 10^{-5} Oe. The unpolarized beam II was intensity-modulated by modulating the amplitude of the high-frequency oscillations of the spectral-lamp generator. The modulation depth ϵ was much less than unity in these experiments.

Resonance signals were observed at the frequency Ω when the constant magnetic field was scanned near the values $\omega_0=0$ and $\omega_0=\pm\Omega$ (Fig. 1). We see that the signal intensity at fixed ϵ depends on the frequency Ω, as is manifest in the considerable growth of the signal amplitude when Ω is decreased. We observed also resonance signals at the frequency 2Ω.

Figure 2 shows plots of the signal amplitude in the field $\omega_0=0$ against the modulating voltage at various frequencies Ω. The plots are linear, in full agreement with the predictions of theory at $\epsilon\ll 1$.

We note in conclusion that the present results are in full agreement with those of a recent paper[2] dealing with the possibility of resonance excitation by modulating the time of collision relaxation of optically-oriented atoms in a transverse magnetic field (parametric relaxation resonance).

[1]E. B. Aleksandrov, O. V. Konstantinov, V. I. Perel', and V. A. Khodovoĭ, Zh. Eksp. Teor. Fiz. 503 (1963) [Sov. Phys.-JETP 18, 346 (1964)].
[2]A. I. Okunevich, *ibid.* 66, 1578 (1974) [39, No. 5 (1974)].