under the conditions of our experiments the decay time of a plasma with $T_e \sim T_i \sim 1$ keV differs only slightly from the case $T_e \gg T_i$.

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PARAMETRIC RESONANCE IN AN EFFECTIVE FIELD

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Submitted 4 August 1966
ZhETF Pis'ma 4, No. 10, 393-396, 15 November 1966

According to classical theory of magnetic resonance, the moment of a spin system acted upon by a constant magnetic field $\vec{H}_0$ and by a radio-frequency field $\vec{H}_1 \cos \omega t$ perpendicular to it executes forced precession with frequency ω around the direction of the field $\vec{H}_0$. When the frequency ω is close to $\omega_0 = \gamma H_0$, resonant absorption of energy from the field $H_1(t)$ is observed. The stationary precession at frequency γH_e, determined by the effective field $H_e = [(H_0 - \omega/\gamma)^2 + H_1^2]^{1/2}$, is not observed in experiments on magnetic resonance, owing to the isotropic distribution of the precessing dipoles in the field H_e. To observe resonance in the effective field at a frequency $\omega_e = \gamma H_e$ it is necessary to apply to the spin system an additional field at a frequency capable of introducing coherence in the motion of the individual spins in the effective field. This can be attained with an oscillating rf field $\vec{H}_2(t)$ parallel to $\vec{H}_0$. The field $\vec{H}_2(t)$ can be resolved into two components, one perpendicular and the other parallel to H_e. The resonance due to the perpendicular component was observed earlier [1] and by now has been well studied. The $\vec{H}_2(t)$ component oscillating along the effective field is usually disregarded, but it is easy to see that its effect differs little qualitatively from the effect of modulating the field H_0 at frequencies that are multiples of ω_0, an effect known in the literature as "parametric resonance." [2].

In this note we report observation of parametric resonance in the effective field. For simplicity, we consider a case when the effective field is of the form $H_e = H_1$, i.e., the case of exact resonance in the laboratory frame. The field component oscillating along the $\vec{H}_e$ direction can be readily produced by amplitude-modulating the field $\vec{H}_1(t)$:

$$H_1(t) = 2H_1(1 + m \cos \Omega t) \cos \omega t. \tag{1}$$

A theoretical analysis based on the Bloch equations shows that modulation of the effective field leads to the appearance of additional motion of magnetic dipoles at frequencies $\omega_0 + n\Omega$. If the relaxation times are equal, $T_1 = T_2 = T$, we can obtain the following equations for the transverse and longitudinal magnetization components:

$$M_x + iM_y = -i(M_0/T)\exp\{i\omega t\} \sum_{k,l} (-1)^k J_k(m\omega_1/\Omega) J_l(m\omega_1/\Omega) \,\mathrm{Im}\left\{\frac{\exp[i(k+l)\Omega t]}{1/T + i(k\Omega - \omega_1)}\right\},$$

$$M_z = (M_0/T) \sum_{k,l} (-1)^k J_k(m\omega_1/\Omega) J_e(m\omega_1/\Omega) \,\mathrm{Re}\left\{\frac{\exp[i(k+l)\Omega t]}{1/T + i(k\Omega - \omega_1)}\right\}, \tag{2}$$

where $J_k(m\omega_1/\Omega)$ is a Bessel function and Ω the rf field modulation frequency. We see that at fixed $\omega_e = \omega_1$ the resonance is expected at frequencies $\Omega = \omega_e/n$, $n = 1, 2, 3, \ldots$

To check on the theoretical conclusions, an experiment was performed on optically oriented Cs^{133} vapor at room temperature. The experimental setup was similar in its main features to that described earlier [3]. The rf field frequency ω and the magnetic field intensity H_0 satisfied the condition $\omega - \gamma H_0 = 0$. The field amplitude $H_1(t)$ was modulated by an audio generator (ZG-10) whose frequency could be varied continuously with a geared synchronous motor. The resonance signal was obtained from the change in the depth of modulation at frequency Ω of the intensity of light passing parallel to $\vec{H}_0$ through the cell (registration of the M_z component of the magnetization).
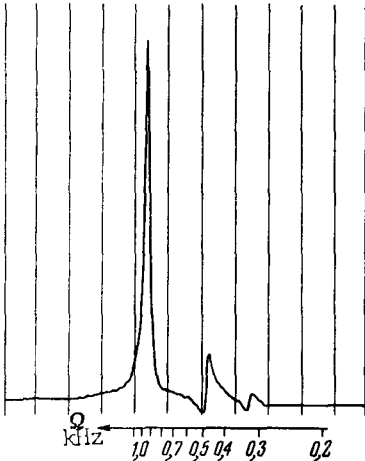

Fig. 1.   Parametric resonance of
Cs^{133} in an effective field
$He = H_1 = 2.74 \times 10^{-3}$ Oe.

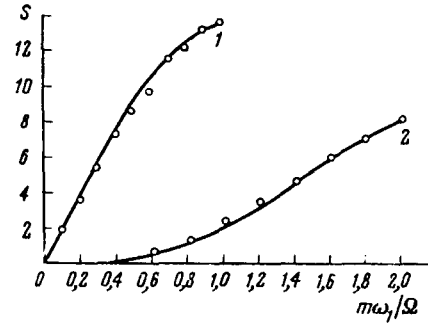Fig. 2.   Parametric resonance signal
vs. relative depth of modulation of
rf field.   Curve 1 – resonance $\Omega = \omega_e$,
curve 2 – resoance $\Omega = \omega_e/2$.   The
ordinates represent the resonance
signal in relative units.

As shown in Fig. 1, resonances were observed at 960, 480, and 320 Hz, corresponding exactly to the values of $\omega_e/2\pi$, $\omega_e/4\pi$, and $\omega_e/6\pi$ at the given amplitude of the rf field.   The asymmetry of the resonance curves and the distortion of the form of the multiple resonances are due to the nonlinearity of the sweep of the modulation frequency and to the phase-frequency dependence of the synchronous detector.

Figure 2 shows the resonance signals at frequencies ω_e and $\omega_e/2$ as functions of the depth of modulation of the rf field.   According to (2), M_z ~ $J_0 J_1$ for the resonance $\Omega = \omega_e$ and M ~ $J_1 J_2$ for the resonance $\Omega = \omega_e/2$.   These relations are shown in the figure by continuous curves, on which the experimentally obtained values are marked by points.

We see from Fig. 1 that the observed resonances are characterized by a very small line width, equal approximately to 60 cps (for comparison we note that the minimum line width of ordinary resonance under laboratory conditions is ~250 Hz); this is characteristic of parametric resonance in which there is no saturation [2].

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SINGULARITIES OF TRANSVERSE MAGNETORESISTANCE OF SINGLE-CRYSTAL GADOLINIUM

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Submitted 6 August 1966
ZhETF Pis'ma 4, No. 10, 396-400, 15 November 1966

It is known [1,2,5] that the direction of the easy-magnetization axes of gadolinium vary rapidly with temperature below the Curie point, and assume all intermediate values between the [0001] axis and the basal plane. According to previously published data [1,2], a "cone" of easy-magnetization axes exists in two temperature regions, from 0 to ~160°K and from ~230 to ~250°K, at temperatures from ~160 to ~230°K the easy-magnetization axes lie in the (0001) plane, and finally above 350°K the gadolinium is a uniaxial ferromagnet with easy axis [0001]. It was therefore of interest to investigate the effect of a change in the magnetic structure on the anisotropy of the transverse magnetoresistance of single-crystal gadolinium in a wide range of temperatures.

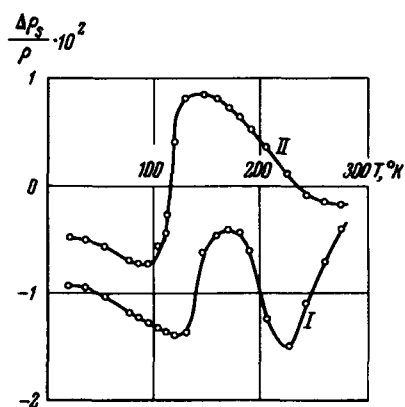We investigated a cylindrical sample cut along the [10$\bar{1}$0] axis, with diameter 1.00 ± 0.05 mm and length 12 mm, prepared by the electric-spark method. The sample was oriented by the Laue method accurate to ±2°. The ratio of the resistances at room and helium temperatures was $R_{293°K}/R_{4.2°K}$ = 20. The resistance was measured by a potentiometer method using a cryostat to maintain the required temperature accurate to 0.2°K.

The isotherms of the transverse magnetoresistance were measured in fields sufficient to produce saturation, and extrapolated to zero field in the sample, equal to $2\pi I_s$ (I_s = saturation magnetization), to exclude the resistance variations due to the paraprocess. The values of the saturation magnetization used to determine the demagnetizing field were taken from [4].

Figure 1 shows the measured temperature dependence

Fig. 1. Temperature dependence of the transverse magnetoresistance of single-crystal gadolinium for two magnetic field orientations: I - H ‖ [11$\bar{2}$0], II - H ‖ [0001].