EFFECTS DUE TO THE INERTIA OF THE MAGNETIC MOMENT[1)]

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It is demonstrated that the influence of the magnetic moment on the interaction between an electromagnetic wave and a plate magnetized perpendicular to its plane leads to a number of new effects. Owing to the presence of an inertial field, resonance phenomena can also be observed when the direction of circular polarization of the electromagnetic wave (which is propagated perpendicular to the plate) is opposite the direction of free magnetization procession. This may result in vanishing of the real part of the magnetic susceptibility for waves of both polarizations, to a two-fold (or three-fold) change in the direction of rotation of the polarization plane and to other effects arising when the electromagnetic wave is transmitted or reflected.

THE inertial field $\mathbf{H}_{in}$ introduced into the equation of motion of the magnetic moment[1] (see the paper by Ginzburg[2]) can exert a noticeable influence on resonance phenomena.[3] Allowance for the inertial field leads to a shift of the resonance frequency, and under certain conditions also to the appearance of resonance in the case when the direction of rotation of the pump field is opposite to the direction of free precession.

We consider here the influence of $\mathbf{H}_{in}$ on the interaction between an electromagnetic wave and a thin plate magnetized perpendicular to its plane.[2)] The components of the permeability tensor μ_{ik}, defined with allowance for its inertial field (without account of losses), are

$$\mu_{11} = \mu_{22} = 1 + \frac{4\pi\gamma M_0(\omega_0 - s\omega^2)}{(\omega_0 - s\omega^2)^2 - \omega^2}, \tag{1}$$

$$\mu_{12} = -\mu_{21} = \frac{4\pi\gamma M_0\omega i}{(\omega_0 - s\omega^2)^2 - \omega^2}. \tag{2}$$

Here M_0 is the magnetization which is directed along the z axis, γ the gyromagnetic ratio, $\omega_0 = \gamma H_0 = \gamma(H_e - H_d)$, H_e the external field, H_d the demagnetizing field, $s = \eta\gamma M_0 V$, η the inertia parameter introduced by Ginzburg, and V the volume of the body. When $s \to 0$ the tensor components take the usual form.[5]

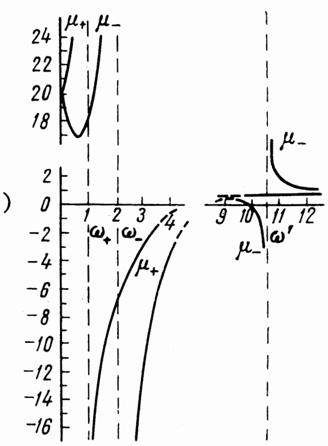

FIG. 1. Dependence of $\mu_\pm(\omega)$ at $\omega_0 = 1.8 \times 10^9$, M_0 = 150 G and $\omega_s = 1.2 \times 10^9$.

For plane circularly-polarized electromagnetic waves propagating along the z axis, the permeability for right-hand rotation is

$$\mu_+ = \mu_{11} - i\mu_{12} = 1 + 4\pi\gamma M_0 / (\omega_0 - \omega - s\omega^2), \tag{3}$$

and for left-hand rotation

$$\mu_- = \mu_{11} + i\mu_{12} = 1 + 4\pi\gamma M_0 / (\omega_0 + \omega - s\omega^2). \tag{4}$$

Both relations have a resonant character.[3)] The resonance frequencies are

$$\omega_\pm = (\omega_s^2/4 + \omega_s\omega_0)^{1/2} \mp \omega_s/2, \tag{5}$$

where $\omega_s = 1/s$ (if $\omega_0 \ll \omega_s/4$, then $\omega_+ \approx \omega_0$ and $\omega_- \approx \omega_s$). A plot of $\mu_\pm(\omega)$ with ω_0 = const is shown in Fig. 1. The reversal of the sign of $\mu_-(\omega)$

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1)Reported at the All-union Conference on the Physics of Ferro-magnetism and Antiferromagnetism, Sverdlovsk, 1965.

*Deceased.

2)The value of $\mathbf{H}_{in}$ for a thin disk was determined in[4].

3)For the existence of a resonance variation of μ_- it is necessary that ω_0 be much smaller than γM_0 and $\omega_s \ll c/r_0$[3]. The first condition determines the choice of the shape of the body, and the second the dimensions.

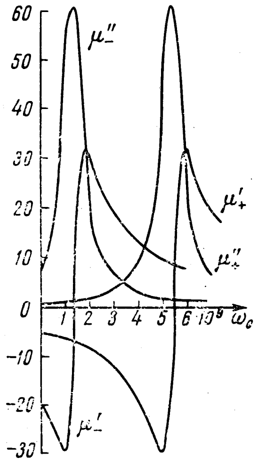

FIG. 2. Dependence of $\mu'_\pm(\omega_0)$ and $\mu''_\pm(\omega_0)$ for $\omega = 2 \times 10^9$, $M_0 = 150$ G, $\omega_s = 1.2 \times 10^9$, $\alpha + \beta\omega^2 = 3.5 \times 10^{-7}$.

at the frequency $\omega' \approx c/r_0$, where r_0 is the linear dimension of the body and c is the speed of light, is due to the rapid decrease of s on approaching the frequency where retardation effects become significant.

If ω = const, with

$$\omega_s < \omega \ll c/r_0, \tag{6}$$

then the resonance fields are

$$H_0^\pm = (s\omega^2 \pm \omega)/\gamma. \tag{7}$$

We shall henceforth assume that condition (6) is satisfied.

If the dielectric constant ϵ is a scalar quantity, then expressions (3) and (4) enable us to write out immediately the refractive indices $n_\pm$ and the expression for the angle of rotation of the polarization plane of the linearly-polarized wave. When the conditions are satisfied for the existence of resonance at the frequency ω_-, the change in direction of rotation of the plane of polarization can be observed not only near the frequency ω_+, but also near ω_- and ω'.

We now analyze the effect with allowance for losses.[4] If we write the equation of motion of the magnetic moment in the form[6]

$$\dot{\mathbf{M}} = -\gamma[\mathbf{M}, \mathbf{H}_0 - \alpha\dot{\mathbf{M}} + \beta\ddot{\mathbf{M}} - \eta\dddot{\mathbf{M}}], \tag{8}$$

then $\mu_\pm = \mu'_\pm + i\mu_\pm$, where

$$\mu_\pm' = 1 + \frac{4\pi\gamma M_0(\omega_0 \mp \omega - s\omega^2)}{(\omega_0 \mp \omega - s\omega^2)^2 + [\gamma M_0 V\omega(\alpha + \beta\omega^2)]^2}, \tag{9}$$

$$\mu_\pm'' = \frac{4\pi\gamma^2 M_0^2 V\omega(\alpha + \beta\omega^2)}{(\omega_0 \mp \omega - s\omega^2)^2 + [\gamma M_0 V\omega(\alpha + \beta\omega^2)]^2} \tag{10}$$

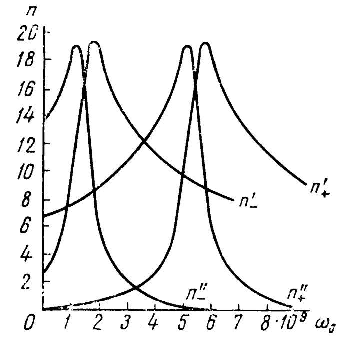

FIG. 3. Dependence of $n'_\pm(\omega_0)$ and $n''_\pm(\omega_0)$ for $\omega = 2 \times 10^9$, $M_0 = 150$ G, $\omega_s = 1.2 \times 10^9$, $\alpha + \beta\omega^2 = 3.5 \times 10^{-7}$, $\epsilon = 9$.

(α and β are dissipation parameters).

From (9) and (10) we see that the dependence of both μ'_+, μ''_+ and μ'_-, μ''_- on ω with ω_0 = const (or on ω_0 with ω = const) has a resonance character. (We note that μ'_- as well as μ'_+ can go through zero.) Plots of $\mu'_\pm(\omega_0)$ and $\mu''_\pm(\omega_0)$ have the form shown in Fig. 2.

The real and imaginary parts of the refractive indices can be expressed in the following manner:[7]

$$n_\pm' = \left[\frac{1}{2}\varepsilon\left(\sqrt{\mu_\pm'^2 + \mu_\pm''^2} + \mu_\pm'^2\right)\right]^{1/2},$$

$$n_\pm'' = \left[\frac{1}{2}\varepsilon\left(\sqrt{\mu_\pm'^2 + \mu_\pm''^2} - \mu_\pm'^2\right)\right]^{1/2} \tag{11}$$

(we neglect the imaginary part of ϵ). Plots of $n'_\pm(\omega_0)$ and $n''_\pm(\omega_0)$ for ω = const are shown in Fig. 3. We see from these plots that the change in the parameters of the waves for both right-hand and left-hand polarizations has a resonant character. Near the resonance fields $H_0^\pm$, intense absorption of the wave of the corresponding polarization takes place. We note that, generally speaking, the possibility of double reversal of direction rotation of the plane of polarization is not excluded.

When an electromagnetic wave is incident on a thin plate magnetized perpendicular to its plane, the change in the ellipticity of the transmitted and reflected waves and the angle of rotation of the ellipse axis can be readily determined by the methods described in [8,9], using expressions (9) and (10) of the present paper.

[4]The conditions for the existence of "left-hand" resonance in the presence of losses were obtained in[3].

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