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MAGNETIC DOUBLE REFRACTION OF MICROWAVES IN PARAMAGNETICS

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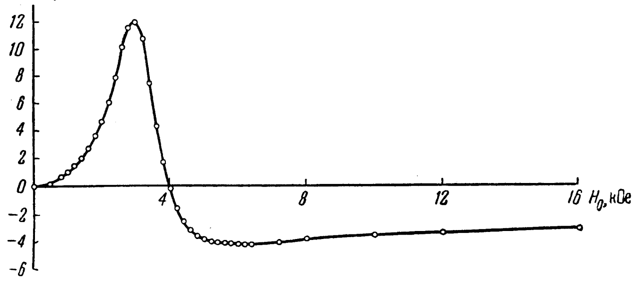
THE rotation of the plane of polarization of the H_{11} wave was studied at a frequency of 9375 megacycles in a circular waveguide filled with a paramagnetic salt. The directional dependence of the external static magnetic field H_0, applied perpendicularly to the direction of propagation of the radio wave was investigated. As a polarizer, we employed a smooth transition of a standard rectangular waveguide to the circular (d = 23 mm). For an analyzer, we used a rotating turnstile junction, two arms of which were connected to a matched load, while at the two others were placed crystal detectors with approximately equal characteristics, connected in opposition by a bridge circuit. Balancing of the system was observed on a type M-95 galvanometer. Because of the small values of the angles of rotation observed, the mechanical rotation of the turnstile junction was employed only for calibration of the scale of the galvanometer.

2. It was established that the angle of rotation $\Delta\psi$ does not depend on the sign of $\mathbf{H}_0$, but does depend on the angle ψ which the field $\mathbf{H}_0$ forms with the magnetic field H of the radio wave before establishing it in the paramagnetic according to the law $\Delta\psi \sim \sin 2\psi$, so that the maximum effect was observed for $\psi = 45°$. As an example, we have shown the curve of the specific rotation of a powdered specimen $MnCl_2H_2O$ in the Figure.

3. The observed laws can be understood if we assume that the rotation of the plane of polarization takes place as a consequence of the anisotropy of the magnetic susceptibility μ. There is then a difference of the phenomenon under consideration



from the ordinary (optical) Cotton-Mouton effect, which is determined by the anisotropy of the constant ϵ.

It is known that the tensor of the high frequency magnetic susceptibility of a paramagnetic magnetized along the z axis has the form:

$$\{\chi\} = \begin{Bmatrix} \chi & -i\delta & 0 \\ i\delta & \chi & 0 \\ 0 & 0 & \chi_z \end{Bmatrix},$$

where χ, δ, χ_Z are complex quantities dependent on H_0, the frequency of the radio wave ω and the relaxation time τ in the paramagnetic. A calculation carried out by one of the authors shows that in the case of wave propagation perpendicular to the applied field, the rotation angle (for not very small ψ) is given by

$$\Delta\psi = -(\pi\omega\sqrt{\varepsilon}/c)\, l\, \{\chi'' - \chi_z''\} \sin 2\psi. \quad (1)$$

Here l is the thickness of the layer of the paramagnetic, χ'' and χ_Z'' are the imaginary parts of χ and χ_Z. The calculation is carried out for free space; ϵ was considered real. As is known, χ'' and χ_Z'' are the absorption coefficients for the cases $H_0 \perp H$ ("perpendicular field") and $\mathbf{H}_0 \parallel \mathbf{H}$ ("parallel field"), respectively, and do not depend on the sign of $\mathbf{H}_0$.

4. Some of the qualitative regularities pointed out in Sec. 2 have already been observed by other authors.[1,2] As concerns the form of the curve $\Delta\psi(H_0)$, it was not observed in sufficient detail.

For $H_0 = 0$, $\Delta\psi = 0$, since $\chi'' = \chi_Z''$. It is also known that at frequencies of the order of 10 kilomegacycles, χ'' has a well-defined maximum at $\gamma H_0 = \omega$ and practically disappears for $\gamma H_0 > (2-3)\omega$, while χ_Z'' decreases slowly and monotonically with increase in H_0.[3] This suffices to explain the observed form of the curve in the Figure. A quantitative estimate on Eq. (1) shows excellent agreement with experimental data.

5. At the present time, the theory does not give precise expressions for χ'' and χ_Z'' in solids. In order to obtain some estimate of these quantities, we can make use of the theory for a paramagnetic gas, consisting of monatomic atoms with spin $\frac{1}{2}$.

We found that in this case,

$$\chi'' = \frac{\chi_0}{2}\left\{\frac{\omega/\tau}{(\omega_0-\omega)^2+\tau^{-2}} + \frac{\omega/\tau}{(\omega_0+\omega)^2+\tau^{-2}}\right\}; \ \chi_z'' = \chi_0\frac{\omega/\tau}{\omega^2+\tau^{-2}} \quad (2)$$

(χ_0 = static susceptibility).

We note that the thermodynamic theory of Shaposhnikov evidently leads to the same formulas (see Ref. 4). If we consider that τ increases with increase in H_0,[3,5] then it is shown that the simple equations (2) provide both a qualitative and a quantitative description of the experimental results.

6. Considerations carried out above show that the magnetic double refraction of microwaves in paramagnetics ("the microwave effect of Cotton-Mouton") is closely connected with the paramagnetic absorption in perpendicular and parallel fields and, together with the paramagnetic resonance rotation,[6-9] enters into a series of phenomena which can now be united under the general title of "paramagnetic resonance."[10]

A more detailed explanation of the results obtained will be published separately.

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TOTAL CROSS SECTION OF STRIPPING AND DIFFRACTION DISINTEGRATION OF FAST DEUTERONS ON NONSPHERICAL NUCLEUS

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Let us consider a nucleus having the form of an ellipsoid of rotation and one that is opaque for incident nucleons. The kinetic energy of the deuterons must be sufficiently large in order that the wavelength of the deuteron be many times smaller than the radius of the nucleus. We shall neglect the effect of the Coulomb field of the nucleus in this note.

With the help of a method developed by Akhiezer and Sitenko,[1] the following expression is obtained for the amplitude of elastic diffraction scattering of deuterons on a nucleus with a fixed orientation of its axis ω:

$$f(\varkappa,\omega) = 2\pi ik\left\{\frac{4p}{\varkappa'}\tan^{-1}\frac{\varkappa'}{2p}\,\Omega(\varkappa',\omega) - \frac{1}{b^2}\int dg\,\frac{2p}{|2g-\varkappa'|}\tan^{-1}\frac{|2g-\varkappa'|}{2p}\,\Omega(g,\omega)\,\Omega(\varkappa'-g,\omega)\right\}, \quad (1)$$

$$\Omega(\varkappa,\omega) = (b^2/2\pi)\,\xi(x)\,J_1(t)/t,$$

$$\cos\vartheta = x;\quad t = \varkappa'\left[\xi^2(x)\cos^2(\varphi-\phi) + \sin^2(\varphi-\phi)\right]^{1/2};$$

$$\xi(x) = \left[\left(\frac{a}{b}\right)^2(1-x^2) + x^2\right]^{1/2}.$$

Here a, b = semiaxes of the ellipsoid, while a refers to the axis of rotation; $\omega = (\theta,\varphi)$ = angles defining the orientation of the nucleus in space; $J_1(t)$ is the Bessel function of order 1; κ = transverse momentum obtained by the deutéron upon scattering; $\kappa = k\theta$; (θ,φ) = direction of the momentum of the scattered deuteron; $\kappa' = \kappa b$; $p = b/R_d = 2\alpha b$.

Equation (1) is simplified when the radius of the nucleus is much larger than the radius of the deuteron and the scattering angles are small ($p \gg 1$, $p \gg \kappa'$). In particular, the forward scattering amplitudes are

$$f(0,\omega) = \frac{ika^2\xi}{2}\left[1 + \frac{1}{\pi p}E\left(\frac{\pi}{2},\frac{\sqrt{\xi^2-1}}{\xi}\right)\right], \quad (2)$$

where E is the complete elliptical integral. Averaging over the various orientations of the nucleus, we obtain the total cross section of all processes:

$$\sigma_t = \frac{4\pi}{k}\overline{\operatorname{Im} f(0,\omega)} = 2\pi b^2\left(1+\frac{\varepsilon}{6}-\frac{\varepsilon^2}{15}\right) + \pi bR_d\left(1+\frac{\varepsilon}{6}-\frac{\varepsilon^2}{40}\right) \quad (3)$$