Diffraction of light by parametric magnons

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Diffraction of light by spin waves with wave numbers $\sim 3\times 10^3$–1.2×10^4 cm^{-1} has been observed in experiment. Unusual forms of the polarization characteristics and a nonlinear character of the dependence of the intensity of the diffracted radiation on the microwave power have been noted and indicate that the diffraction is by spin waves that are parametrically excited under conditions close to the fundamental resonance.

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The behavior of a spin system beyond the threshold of parametric excitation has attracted attention for a long time and has been the subject of numerous discussions.[1,2] The investigation of an excited system of magnons by traditional microwave-spectroscopy methods, however, is difficult because the data obtained by these methods are indirect and lend themselves to ambiguous interpretation. More effective in this case are magneto-optical methods, which make it possible to determine directly the above-threshold characteristics of a system of parametrically excited magnons.[3–5] Such a method was used successfully, in particular, to investigate processes in the region of the additional absorption.[5] We have observed diffraction of light by parametrically excited spin waves (PSW) under conditions close to the fundamental resonance.

We used in the experiments a longitudinally magnetized single-crystal $Y_3Fe_5O_{12}$ prism measuring $10.7\times 3.0\times 2.9$ mm, with edges parallel to the cubic unit cell. The prism was excited at a frequency $f_0 = 1.2$ GHz by a straight wire antenna located at the end face. The microwave generator operated in the pulsed regime (pulse duration 20—500 μsec, repetition frequency 1000 Hz); the maximum peak radiation power was about 1 W. A light beam from an He-Ne laser ($\lambda = 1.15\ \mu$), after passing through a polarizer and a focusing lens ($F \approx 10$ cm) was incident on a sample and was scattered by waves excited in the crystal. To register the diffracted radiation, we used a photodiode and a synchronous-detection system.

We observed additional diffraction maxima at a microwave power exceeding a certain characteristic value P_{cr} (~10 mW), in a diffraction angle interval $3° \lesssim |\theta| \lesssim 12°$ located between the magnetostatic (MSW) ($|\theta| \lesssim 1°$) and the magnetoelastic (MEW) ($20° \lesssim |\theta| \lesssim 23°$) maxima. Figure 1a shows plots of the intensity of the diffracted radiation against the diffraction angle for different values of z (see the insert). It is seen that with increasing distance of the probing point from the center of the sample ($z = 5.35$ mm) the additional maximum broadens and gradually merges with the maximum for the MSW (see the paper on "anomalous diffraction").[4] The dependence of the intensity of the diffracted radiation on the microwave power for both maxima is shown in Fig. 1b. At a power exceeding P_{cr}, a noticable deviation from linearity is observed on the MSW curve and an additional maximum appears, while both plots have a ten-

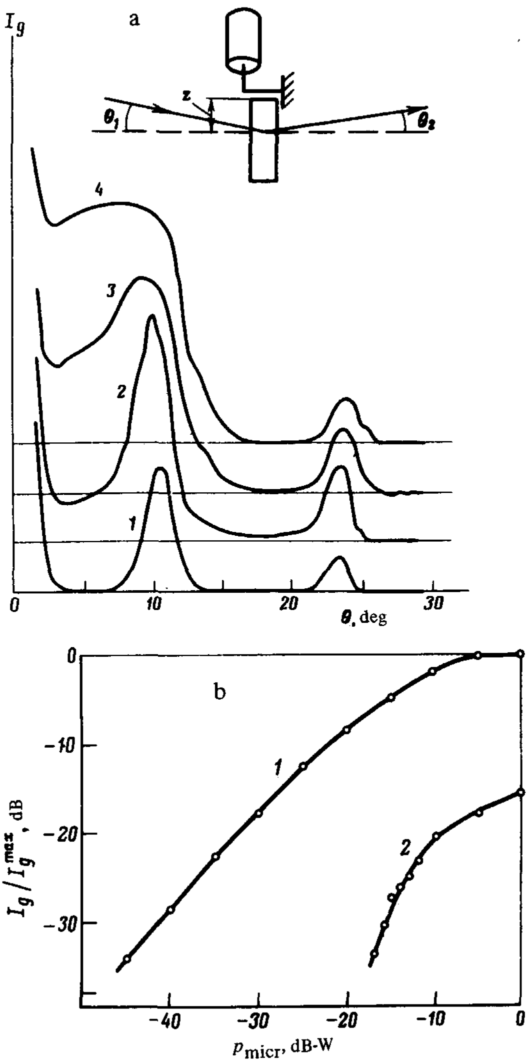

FIG. 1. Dependence of the intensity of the diffracted radiation at $H \approx 580$ Oe: a) on the diffraction angle $\theta = \theta_1 + \theta_2$ at a peak microwave power ~0.3 W at the following values of z (in mm): 1—5.3, 2—5.1, 3—4.9, 4—4.7; b) on the microwave power at $z = 5.1$ mm for the MSW maximum (curve 1) and for the additional maximum ($\theta = 10°$; curve 2).

dency to flatten out with further increase of the power. This allows us to assume that the additional maximum is due to parametric excitation of the spin waves and that the characteristic value P_{cr}, of the microwave power, corresponds to the excitation threshold.

We have investigated also the polarization characteristics of the additional maximum. Figure 2 shows, for different values of the microwave power P,

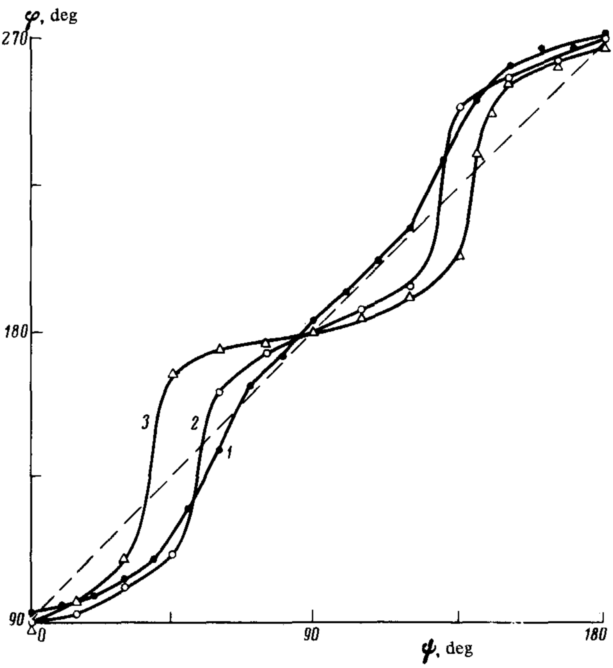

FIG. 2. Polarization characteristics of diffracted radiation at different values of the microwave power. P_{micro}(dB-W): 1—(−14); 2—(−12); 3—0. $z = 5.2$ mm; $H \approx 580$ Oe; $\theta = 10°$.

curves [$\phi(\psi)$] that characterize the connection between the orientation of the major axis of the polarization ellipse of the diffracted wave (ϕ) and the plane of polarization of the incident light (ψ). The angles ϕ and ψ were reckoned from the diffraction plane. At a small (~1 dB) excess above P_{cr}, the polarization characteristics are close in form to those observed earlier for the case of diffraction by MSW.[4,6] With increasing power, the character of the $\phi(\psi)$ dependence changes qualitatively, and it acquires the form of the similar $\phi(\psi)$ dependence for the "anomalous diffraction."[4] No such characteristics can be obtained when light is diffracted by arbitrary coherent elementary excitations in a magnetically ordered crystal.

Additional diffraction maxima were observed in a narrow interval of magnetization fields (where $z = 5$ mm, e.g., $\delta H \lesssim 8$ Oe) near the field value corresponding to resonance for the spin waves with $\theta_k = 0$ at the frequency f_0 at the observation point, and an increase of the field (in the interval δH) shifted the maxima towards smaller diffraction angles (in the interval $3° \lesssim |\theta| \lesssim 12°$).

To determine the direction of the wave vector of the spin waves we investigated the dependence of the intensity of the diffracted light on the angle θ_1 of the incidence of the light on the sample at a fixed diffraction angle $\theta = \theta_1 + \theta_2$. The results of these measurements have shown that the diffraction is by waves with $\theta_k = 0$, and that the width of the angle spectrum $(\Delta\theta_k)_{0.5}$ does not exceed 1°.

The results of our experiments suggest that the appearance of additional diffraction maxima is connected with diffraction by spin waves that are parametrically excited under conditions close to the conditions of the fundamental resonance.[1)] The most probable excitation mechanism is nondegenerate parametric excitation of spin waves with frequencies and wave vectors satisfying the conditions $f_1 + f_2 = 2f_0$ and $\mathbf{k}_1 + \mathbf{k}_2 = 2\mathbf{k}_{MSW}$, the frequencies f_1 and f_2 being close to f_0.[7] The unusual behavior of the polarization characteristics can be explained by recognizing that in parametric excitation of a large number of spin waves, the correlation between the alternating components of the magnetization averaged over the ensemble, $\langle m_x \rangle$ and $\langle m_y \rangle$, is violated.[8] Our calculations for the case of an arbitrary degree of correlation between $\langle m_x \rangle$ and $\langle m_y \rangle$ has shown that for the Stokes component of the diffracted radiation the function $\phi(\psi)$ is given by

$$\phi = \frac{\pi}{2} + \frac{1}{2} \operatorname{arc\,tg} \frac{(\alpha^2 \overline{<m_y>^2} - \beta_2^2 \overline{<m_x>^2}) \sin 2\psi}{(\alpha^2 \overline{<m_y>^2} + \beta_2^2 \overline{<m_x>^2}) \cos 2\psi - 2\alpha\beta_2 \sqrt{\overline{<m_x>^2} \cdot \overline{<m_y>^2}} \cdot r},$$

where α and β_2 are the magneto-optical constants of the first and second order, respectively. At $|r| = 1$ (case of total correlation), this dependence is analogous to that obtained in[6] for coherent spin waves. The $\phi(\psi)$ curves observed in experiment at different values of the microwave power agree well with the theoretical relations if the correlation coefficient $0 < |r| < 1$ is properly chosen, making it possible to draw different conclusions concerning the state of the spin system beyond the excitation threshold from the magnitude of the correlation coefficient.

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[1)] A similar phenomenon was possibly observed in[5], but the results presented there do not permit this conclusion to be drawn unequivocally.

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