Optical investigation of spin and magnetoelastic waves in a single crystal of yttrium iron garnet under longitudinal magnetic pumping

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Inelastic scattering of light is experimentally detected and investigated in a $Y_3Fe_5O_{12}$ crystal under excitation of nonlinear ferromagnetic resonance by the method of longitudinal magnetic pumping. In an external constant magnetic field near the critical value ($H_0 \approx H_{0c}$), the spectrum of the scattered light contains satellites whose frequencies differ from the frequency of the incident light ($\lambda = 6328$ Å) by the amount $\Omega_0/2$ (Ω_0 is the frequency of the microwave pumping field). From measurements of the spatial distribution of the intensity of the scattered light, it follows that the satellites correspond to scattering by parametric magnons having polar angle $\Theta_k = 90°$. Intense scattering of light by quasiparticles with frequency $\Omega_k < \Omega_0/2$ is detected in fields $H_0 \neq H_{0c}$. It is suggested that such quasiparticles originate in the first stage of relaxation of parametric magnons with frequency $\Omega_k = \Omega_0/2$.

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1. INTRODUCTION

At sufficiently high values of an alternating magnetic field, various nonlinear phenomena occur in the magnetic system of magnetically ordered crystals. In particular, these phenomena may be due to the fact that certain spin waves become unstable, i.e., their amplitude increases rapidly, as a result of interaction with the alternating field, at a definite threshold amplitude h_c of that field. The most important form of instability is parametric excitation of a pair of spin waves with wave vectors $\mathbf{k}_1$ and $\mathbf{k}_2$ and with frequencies Ω_1 and Ω_2, respectively, under the action of electromagnetic (or spin) pumping waves with wave vector $\mathbf{k}_0$ and frequency Ω_0.[1-3] For this form of instability, the conservation conditions

$$\nu\mathbf{k}_0=\mathbf{k}_1+\mathbf{k}_2, \quad \nu\Omega_0=\Omega_1+\Omega_2,$$

are satisfied, where $\nu = 1, 2, 3, \ldots$ From this it is evident that the elementary processes underlying these instabilities are disintegrations of one or several pumping photons (or magnons) into two magnons of the potentially unstable oscillations.

Usually the instabilities that have the lowest threshold are those of the first order ($\nu = 1$). If the pump is an alternating magnetic field, i.e. $\mathbf{k}_0 = 0$, then $\mathbf{k}_1 = -\mathbf{k}_2 \equiv \mathbf{k}$, and for the processes with $\nu = 1$

$$\Omega_1=\Omega_2=\Omega_k=\Omega_0/2.$$

Special interest attaches to the first-order instability that occurs under the action of an alternating magnetic field polarized parallel to the constant magnetization (longitudinal pumping). This interest is stimulated by the possibility, in principle, of individual study of magnons having different wave vectors; and this in turn is due to the relatively strong dependence of the threshold pumping field h_c on the angle θ_k between the wave vector of the excited magnon and the direction of the constant magnetization.[2]

Most of the experimental work so far known on investigation of nonlinear phenomena under longitudinal pumping has been done by the radiospectroscopic method. It consists in measurement of the nonlinear high-frequency susceptibility of the crystal and study of its variation with the external constant and alternating magnetic fields H_0 and h, the speciment temperature T, and other parameters. This method has made it possible to obtain much information about the properties of oscillations excited in magnetic crystals, in particular about the relaxation times of spin waves with various $\mathbf{k}$. But the susceptibility, in general, is determined not by some single type of oscillation but by the whole set of oscillations. Therefore in order to obtain from such an experiment the individual characteristics of a specific type of oscillation, it is necessary to introduce a number of assumptions, which are not always sufficiently justified. This is especially important in investigation of beyone-threshold states ($h > h_c$). That is why there is a well-known interest in attempts to apply to the investigation of nonlinear processes such methods as would permit direct determination of the parameters of the excitations in the crystal. In this sense, a quite promising direction is the sutdy of inelastic scattering of light by a parametrically excited crystal. Investigation of the spectrum of the scattered light and of the spatial distribution of its intensity permits, in principle, determination both of the frequency Ω_k of the oscilations and of their wave vector $\mathbf{k}$.

In general, the optical method has already been applied by a number of authors for investigation of magnetic resonance both in ferrites[4-6] and in antiferromagnets.[7] For ferrites, this method consisted in recording, by means of the magnetooptical Faraday effect, the change ΔM of the magnetization of the crystal when it was excited by the pumping field; that is, elastic scattering of light was used. But the value of the magnetization gives information only about the total number of magnons with $k \neq 0$ accumulated in the speciment (parametric, intermediate, and thermal). Of course, traditional radiospectroscopy cannot give such information. Therefore if radio spectroscopic investigations are supplemented by measurements of ΔM by the optical method, new results can be obtained. Work designed

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thus has been done by Le Gall and Jamet[6] on a crystal of yttrium-iron garnet (YIG).

But as has been noted, the change of magnetization is an integral parameter that does not enable one to judge the structure of the spectrum of excited oscillations. Therefore it is still a timely problem to detect and study inelastic scattering of light by parametrically excited waves in magnetic materials. Detection of such scattering under longitudinal pumping in a single crystal of yttrium iron garnet was first reported in a previous paper.[8] We note that an investigation of a similar kind has also been made under transverse pumping in the antiferromagnet $CoCO_3$, where enhancement of thermal magnons was detected at a frequency equal to half the pumping frequency.[9]

2. EXPERIMENTAL METHOD

The present paper is devoted to investigation of inelastic scattering of linearly polarized light, with wavelength $\lambda = 6328$ Å, in a single crystal of yttrium iron garnet, $Y_3Fe_5O_{12}$, under longitudinal magnetic pumping ($\mathbf{h} \parallel \mathbf{H}_0$) with frequency $\Omega_0 = 2\pi \cdot 9100$ MHz. The specimen was magnetized along the direction of the fourth-order crystallographic axis [100]; the incident light was polarized perpendicular to this direction (i.e., to the equilibrium magnetization vector M_s). The experiment recorded the scattered light in the angular interval $0.3° \leq \theta \leq 15°$ with polarization orthogonal to the polarization of the incident light. This corresponded to wave vectors of the scattering quasiparticles over the interval $5 \cdot 10^2 \leq k \leq 2.4 \cdot 10^4$ cm^{-1}. The bounding of the value of k from below is due to the fact that scattering by quasiparticles with smaller wave vectors is masked by magnetic birefringence even for optimal polarization of the incident light. Therefore it was necessary to cut off the transmitted beam with an opaque central diaphragm.

The spectral composition of the scattered light was investigated with a scanning Fabry-Perot interferometer. The light source was a helium-neon laser with $\lambda = 6328$ Å. At this wavelength, the coefficient of light absorption of the crystal is quite large ($\varkappa = 800$ cm^{-1}). This fact determined the form of the specimens investigated: they were plane-parallel plates of thickness $d = 30$ μm and volume $V_s \leq 0.1$ mm^3. The plane of the plates coincided with the crystallographic plane (100). Since the nonlinear high-frequency susceptibility is small (in our case $\chi' < \chi'' < 0.1/2\pi$), it is very difficult to make radiospectroscopic measurements with specimens of such a volume, and we did not make these measurements.

A detailed schematic sketch of the experimental setup is shown in Fig. 1. Light from the laser, passing through the quarter-wave plate QWP and the polarizer P, was focused by the long-focal-length lens L_1 ($f = 600$ mm) on the specimen S in a spot of diameter 0.8 mm. The light scattered in the specimen, after going through the analyzer A, passed through the short-focal-length lens L_2 to the diaphragm D_1, whose plane coincided with the focal plane of this lens. By changing the position of the aperture of the diaphragm D_1 with re-

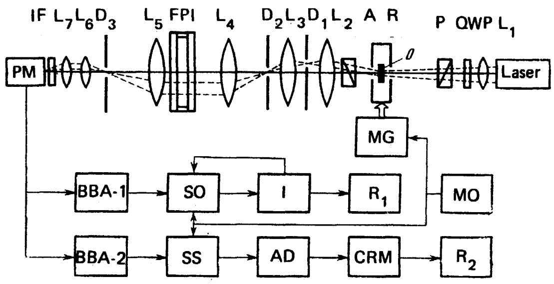

FIG. 1. Schematic diagram of experimental setup for observation of light scattering at small angles to the incident beam. L_1–L_7) lenses; D_1, D_2, and D_3) diaphragms; P) polarizer; A) analyzer; QWP) quarter-wave plate; R) microwave resonator; FPI) Fabry-Perot interferometer; IF) interference filter; BBA-1 and BBA-2) broad-band amplifiers; SO) stroboscopic oscillograph; I) integrator; R_1 and R_2) recorders; SS) selective stage; AD) amplitude discriminator; CRM) counting-rate meter; MO) master oscillator; MG) magnetron generator; S) specimen.

spect to the incident light beam, and also by changing the shape of the diaphragm itself, one could investigate both the angular distribution of the intensity of the scattered light and the scattering spectrum at various angles. After the diaphragm D_1, the light passed through the collimation system L_3, D_2, L_4 and entered the interferometer, with scanning by change of the pressure of the air in the chamber in which the interferometer was located. The light leaving the interferometer was focused by the lens L_5 ($f = 300$ mm) on the diaphragm D_3 (with aperture diameter 0.5 mm) and then, through the auxiliary lenses L_6 and L_7, reached the photocathode of a photomultiplier FÉU-79.

The signal from the photoreceiver was recorded by systems of two types: a system for selective counting of photons and a stroboscopic integrator. The first system was applied principally in the investigation of the spectrum of the scattered light, but in some cases also for measurements of the angular distribution of the scattered radiation. This system has a comparatively high absolute sensitivity.

Since in our experiment the microwave pumping power was modulated by a rectangular pulse of duration $\tau_p = 4$ μsec and repetition frequency $F_p = 250$ GHz, it became possible to use for the recording also a system based on a stroboscopic oscillograph. This recording channel was used for measurement of the parameters both of the pulse component of the intensity of the scattered light and of the pulse change of the specimen magnetization. Here the interferometer was eliminated from the optical system. The change of magnetization was estimated from the corresponding change of the linear magnetic birefringence of light in the crystal during the pumping pulse.[10] The pulse mode of pumping applied in our experiment, first, eliminated pronounced heating of the specimen by the microwave field; and, second, permitted, in principle, observation of the evolution in time of the processes under study.

All measurements reported in this paper were made with the specimen at room temperature.

3. EXPERIMENTAL RESULTS

We first investigated the angular (spatial) distribution of the pulse component of the intensity of the scattered light. We remark that the results presented below were obtained at a quite high intensity of the microwave field: $h\sim 1.5$ Oe. Figure 2a shows the experimental variation of the pulse component of the scattering with the intensity of the constant magnetic field, in the presence of the central diaphragm alone. This variation is determined by the contribution of the quasiparticles with wave vectors lying within the whole measured range. The symbol θ_k' introduced in this figure denotes the angle between the constant magnetization and the projection of the wave vector of the scattering quasiparticle on the plane perpendicular to the incident light beam. We remark that in our experiments the direction of incidence of the light was perpendicular to the plane of the specimen.

As is evident from the figure, the variation found has a quite complicated structure. We turn our attention to the maximum near $H_0=1000$ Oe. It is easy to show that this value of field is close to the value of the internal critical field $H_{1c}=970$ Oe for the known pumping frequency $\Omega_0=2\pi\cdot 9100$ MHz. Figures 2b–e show the variations obtained by use of diaphragms that enable one to isolate the light scattered by quasiparticles with definite values of the angle θ_k' but with different values of k. It is now clearly evident that only in fields close to the critical is the pulse scattering of light caused primarily by quasiparticles propagating perpendicular to the external field, i.e., with $\theta_k'=90°$. Scattering in fields substantially different from the critical occurs on quasiparticles with $\theta_k'\approx 0$.

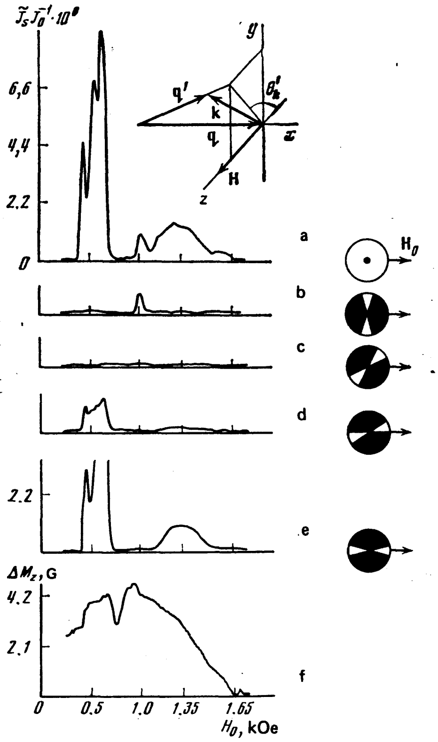

FIG. 2. Variation of the pulse component of the intensity of the scattered light with external magnetic field, for various values of the angle θ_k' of the scattering quasiparticles: a) $0\leqslant\theta_k'\leqslant 360°$; b) $85°\leqslant\theta_k'\leqslant 95°$; c) $40°\leqslant\theta_k'\leqslant 50°$; d) $5°\leqslant\theta_k'\leqslant 15°$; e) $(-5°)\leqslant\theta_k'\leqslant 5°$. Curve f shows the variation of the pulse change of magnetization of the crystal with external magnetic field. The insert at the top of the figure shows the geometry of the scattering under study. In the right part of the figure are shown the diaphragms D_1 (Fig. 1) used to obtain the variations presented.

Figure 2f shows, for comparison, the variation of the pulse change of magnetization of the crystal with the external magnetic field, obtained under the same conditions as the scattering. As is well known, the change of magnetization is proportional to the number of magnons with $k\neq 0$ excited in the specimen. Consequently, the variation shown describes the general level of nonequilibrium excitation of the magnetic system of the crystal.

The next step was a study of the variation of the scattering intensity with the value of the angle θ between the wave vectors $\mathbf{q}$ and $\mathbf{q}'$ of the incident and scattered light, respectively, for fixed values of θ_k'. The measurements were made by means of a diaphragm D_1 (Fig. 1) in the form of an opaque screen with a small aperture, the position of which with respect to the center of the diaphragm could be changed in the course of the experiment. This possibility was provided for by a special construction of the diaphragm used. Since the scattering angle θ, in accordance with the Bragg condition, is uniquely determined by the wave vectors $\mathbf{k}$ of the scattering quasiparticle and $\mathbf{q}$ of the incident light, the dependence of the scattering intensity on θ is easily converted to the corresponding dependence on k. For this purpose, in the case considered, scattering of light by low-frequency acoustic magnons, the formula used was the simple one

$$k=2q\sin(\theta/2).$$

Examples of the experimental dependence of the scattering intensity on θ and on k are shown in Fig. 3. As is evident from this figure, in magnetic fields close to

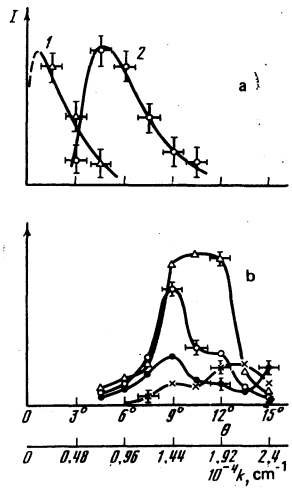

FIG. 3. Variation of the pulse component of the intensity I (in relative units) of the scattered light with scattering angle θ, for fixed H_0 and θ_k': a) $H_0\approx H_{0c}=1050$ Oe, $\theta_k'=90°$ (curves 1 and 2 correspond to two crystallographically equivalent positions of the specimen); b) $\theta_k'\approx 0$, ●) $H_0=549$ Oe, △) $H_0=758$ Oe, ○) $H_0=675$ Oe, ×) $H_0=1350$ Oe.

the critical value (Fig. 3a) the scattering of the light occurs on the long-wavelength oscillations. The relation under discussion has two characteristic features. First, no scattering by quasiparticles with $k \approx 0$, is observed, although according to the definition of the critical field H_c they should be produced. Second, there is observed a strong dependence of the shape of the curves on the orientation of the crystal. This dependence is not due to crystallography, since curves 1 and 2 correspond to equivalent positions of the crystallographic axes: the specimen was rotated through 90° in its plane. Therefore the observed effect is due rather to magnetic inhomogeneity of the crystal.

The scattering in fields different from the critical, as is evident from Fig. 3b, occurs on quasiparticles with wave vectors lying in the interval $1.2 \cdot 10^4 \leq k \leq 2.2 \cdot 10^4$ cm^{-1}; the four relations shown, corresponding to different values of the magnetic field, permit us to suppose the presence of two maxima of intensity near the values $k_1 \approx 1.4 \cdot 10^4$ cm^{-1} and $k_2 \approx 2.0 \cdot 10^4$ cm^{-1}. In this sense the curve in Fig. 3b corresponding to field $H_0 = 758$ Oe may be regarded as a superposition of such maxima with the same intensity. Unfortunately the experimental error in the measurement of the angle θ does not permit us to assert this unambiguously. But a substantial decrease of the angular error is connected with a loss of intensity and did not result, in our experiment, in the obtaining of more reliable results.

Still another distinctive feature of the scattering for $H_0 \neq H_{0c}$ is the identity of the corresponding relations of Fig. 3b for two crystallographically equivalent positions of the specimen. At the same time, the absolute value of the intensity of the scattered light changed by a factor of several on rotation of the specimen.

In order to determine the frequency (energy) of the scattering quasiparticles, the spectrum of the scattered light was investigated experimentally. Figure 4 shows examples of traces of the spectrum for three characteristic values of the external field H_0. In fields

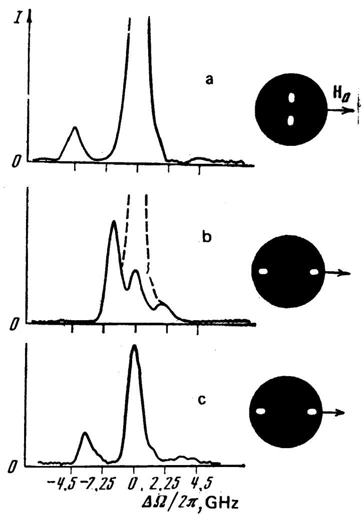

FIG. 4. Spectrum of scattered light at various H_0 and θ_k': a) $H_0 \approx H_{0c}$, $\theta_k' \approx 90°$; b) $H_0 = 675$ Oe, $\theta_k' = 0$ (the dotted curve shows the spectrum when the analyzer is uncrossed by ±1°); c) $H_0 = 1350$ Oe, $\theta_k' \approx 0$. To the right of the figure are shown the diaphragms D_1 (Fig. 1) used to obtain curves a–c.

close to the critical, there are present in the spectrum of the scattered light satellites, whose frequencies differ from the frequency of the incident light by half the the frequency of the microwave pumping field (Fig. 4a); that is, by $\Delta\omega_{1,2} = \pm\Omega_0/2 = \pm 2\pi \cdot 4550$ MHz. Within the limits of experimental error (equal to $2\pi \cdot 300$ MHz), the frequency shift of the satellites is unchanged by rotations of the specimen. Thus at $H_0 \approx H_{0c}$, scattering occurs on quasiparticles with energy $\hbar\Omega_0/2$ and wave vectors (see above) perpendicular to the external magnetic field. In our case, such quasiparticles can be only magnons, since phonons with the indicated energy have wave vectors $k_s \geq 4 \cdot 10^4$ cm^{-1} and cannot be observed in our experiment.

Quite unexpected results were obtained in investigation of the spectrum in fields substantially different from the critical, where, as has already been mentioned, scattering with $\theta_k' \approx 0$ is observed. By use of diaphragms D_1 constructed with allowance for the peculiarities of the spatial distribution of the intensity of the scattered light, we succeeded in resolving the spectrum even in this case (see Fig. 4b, c). As is seen from the figure, both for $H_0 < H_{0c}$ and for $H_0 > H_{0c}$ the spectrum of the scattered light contains satellites. But the frequency shift of these satellites is less than $\Omega_0/2$. The frequency shift in fields less than the critical is especially small, and this prevented us from obtaining the spectrum in our first measurements.[8] For example, at field $H_0 = 675$ Oe ($H_i = 595$ Oe) the shift amounts to only $0.37\Omega_0/2$ (Fig. 4b). Since in small fields the intensity of the unshifted line could be lowered to the intensity level of the satellites, it became possible to demonstrate that the pulse change of intensity of the scattered light was entirely due to the shifted components.

The scattering observed on quasiparticles with $\theta_k' \approx 0$ has the following characteristic features. The frequency shift of the satellites, within the limits of experimental error, corresponds to the lower limit of the spectrum of spin waves for all values of H_0 at which such scattering is observed. Therefore the quasiparticles with $\theta_k' \approx 0$ cannot be excited directly by the high-frequency field, since they are not in parametric resonance with the pump (their frequency $\Omega_k < \Omega_0/2$). The nature of the quasiparticles produced when $H_0 \neq H_{0c}$ will be discussed in more detail in Section 4 of the present paper.

So far, we have been concerned with measurements made at a fixed and sufficiently high pumping power. But a definite interest attaches also to the dependence of the parameters of the excited quasiparticles on the pumping level. One of these parameters is their occupation numbers n_k. For parametric magnons, the mean value of n_k, and consequently also the corresponding change of magnetization of the crystal, equal to $\Delta M_k = \gamma\hbar n_k$, can be estimated from the intensity of the light scattered by these magnons. In our experiment, such an estimate was made from the intensity of the Stokes component in the spectrum of the scattered light; the formulas used in the calculations were those for inelastic scattering of light by magnons with $k = 0$ (see, for example, Ref. 10), which are valid also in the case of scattering by magnons with $k<q$. The variation thus found of the pulse change of magnetization ΔM_k, due to production of parametric magnons with $\Omega_k=\Omega_0/2$ and with $\theta_k\approx 0$, with the pumping power is shown in Fig. 5 (Curve 1). The same figure shows the variation of the total pulse change of magnetization ΔM_σ, caused by all the nonequilibrium magnons with $k\neq 0$, with the pumping power (Curve 2). The estimate of ΔM_σ was made from the value of the pulse change of the linear magnetic birefringence of light in the crystal. Noteworthy is the noncoincidence of the threshold fields for ΔM_σ and ΔM_k:

$$h_c^{(k)}/h_c^{(\sigma)}=2.34.$$

As it turned out, the maximum excess over the threshold for magnons satisfying the conditions for light scattering did not, in our experiment, exceed the value $h_{max}/h_c^{(k)}-1\approx 0.2$; that is, it was comparatively small. It is necessary also to mention the linear variation both of the value of ΔM_σ and of the value of ΔM_k with the pumping power near the thresholds. This result agrees qualitatively with the results of Ref. 6 already mentioned.

In Section 2 of the present paper it was noted that the mode of pulse modulation of the microwave pumping power was applied in the experiment. This permitted us to attempt to follow the evolution of the process of excitation of quasiparticles in time. Figure 6 shows oscillograms of the pulses from the photoreceiver; these describe the dynamics of this process. The oscillograms were obtained at the maximum pumping field $h=h_{max}$. We note that the form of signals b and c in Fig. 6 was primarily determined by the time constant of the photoreceiver ($\tau_{phr}\sim 0.5$ μsec) and therefore contained no useful information. In this sense the last oscillogram (Fig. 6e) is attractive; it reflects the growth of the number of parametric magnons when $H_0\approx H_{0c}$. It is evident that the accumulation of magnons on which light scattering was observed occurs quite slowly in comparison with the growth of the total number of nonequilibrium magnons with $k\neq 0$ (Fig. 6c). The parametric magnons do not even reach their stationary level during the whole span of the pumping pulse ($\tau_p=4$ μsec). Only during the first two microseconds is an

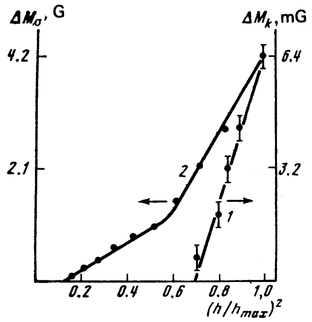

FIG. 5. Variation of the pulsed changes of magnetization of the crystal with pumping power. Curve 1, the change caused by production of magnons with $\theta_k'=90°$, satisfying the conditions for scattering of light. Curve 2, the change caused by all nonequilibrium magnons. External field $H_0\approx H_{0c}$.

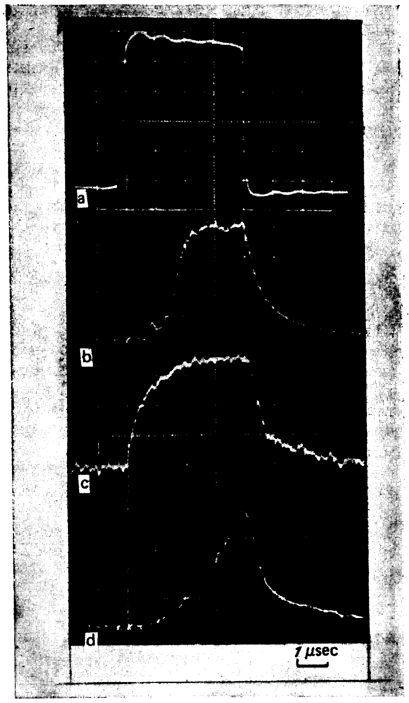

FIG. 6. Oscillograms of pulses from the photoreceiver: b) scattering at $H_0=675$ Oe ($\theta_k'\approx 0$); c) pulse change of birefringence of light; d) light scattering at $H_0\approx H_{0c}=1050$ Oe ($\theta_k'\approx 90°$). Oscillogram (a) is the pumping pulse.

exponential growth of the number of magnons observed; thereafter, it slows down and proceeds further approximately in accordance with a linear law.

By using the initial exponential section of the oscillogram of Fig. 6e, we shall estimate the relaxation frequency η_k of parametric magnons, starting from the well-known formula (see, for example, Ref. 11)

$$n_k=n_{kT}\exp[2\eta_k(h/h_c-1)t], \qquad (1)$$

where n_{kT} is the thermal level of parametrically amplified magnons. This frequency was found to be $2\eta_k\approx 1.1\cdot 10^7$ sec^{-1}, which corresponds to $2\Delta H_k=2\eta_k/\gamma=0.6$ Oe.

In concluding this section, we shall make a remark regarding the determination of the internal field in the specimen. The correction ΔH was determined experimentally by measurements of the position of the ferromagnetic resonance line and was found to be $-(80\pm 10)$ Oe. The principal contribution to this correction comes from the magneto-crystalline anisotropy field, since the demagnetizing field, calculated by formulas offered in Ref. 12 for specimens in the form of thin plates, amounted to only ~ -9 Oe.

4. DISCUSSION OF RESULTS

Before proceeding directly to the discussion of the results obtained, we shall consider the spectrum of long-wavelength volume magnons in a thin ferrite plate magnetized in its plane. This spectrum can be found by starting from the spectrum of exchangeless magnetostatic waves,[13]

$$\Omega_k^2=\Omega_H\left[\Omega_H+\frac{\Omega_m}{1+(k_zd)^2/[(k_yd)^2+X_n^2]}\right], \qquad (2)$$

where $\Omega_H=\gamma H_i$, $\Omega_m=4\pi\gamma M_s$, and $X_n=k_xd=n\pi$ (the coordinate system used here is shown in Fig. 7b). In order to take account of the energy of nonuniform exchange, it is sufficient to make the following substitution in (2):

$$\Omega_H\rightarrow\Omega_H+\Omega_e(ak)^2; \qquad (3)$$

here $\Omega_e=\gamma H_e$, where H_e is the exchange field, and a is the lattice constant of the crystal. Expressions (2) and (3) determine the desired spectrum. Characteristic features are a sinusoidal distribution of the amplitude of precession along the x axis and a negative dispersion at $k\sim 0$ for magnons with $\theta_k'\neq 0$. An example of such a spectrum, for the case $H_0=H_{0c}$, is shown in Fig. 7a (Curves 1, 2, and 2′). The points denote experimental values (for two orientations of the specimen), corresponding to the maxima on Curves 1 and 2 of Fig. 3a and to the spectrum of Fig. 4a.

Thus in fields close to the critical, we observe production of long-wavelength magnons with wave vectors perpendicular to the external magnetic field ($\theta_k'=90°$, which in this case is equivalent to $\theta_k=0$). These magnons, under conditions of longitudinal pumping, correspond to the minimum value of the threshold field, as follows from the well-known expression[2]

$$h_c=2\Delta H_k\Omega_0/\Omega_m \sin^2\theta_k, \qquad (4)$$

where $\Delta H_k=\eta_k/\gamma$ is the attenuation parameter of magnons with wave vector **k**.

Furthermore, the condition of conservation of quasimomentum in events of single-magnon scattering of light uniquely determines the orientation of the wave fectors of the scattering magnons in the scattering plane. In the case under consideration, this plane is perpendicular to the external magnetic field (Fig. 7b), and the angle between the wave vector **k** of the scattering magnon and the y axis is $\varphi_k=\theta/2$. According to Fig. 3a, in our experiment $\varphi_k\lesssim 5°$; that is, the magnons with $\theta_k'=90°$ observed in light scattering are propagated practically along the plane of the specimen. Here the distribution of the amplitude of precession of the magnetic moment through the thickness of the specimen (along the x axis) is not sinusoidal. In fact, it follows from expression (2) that for volume spin waves in a plate of thickness 30 μm the minimum value of k satisfying the Bragg condition corresponds to $n=1$ and is $k_1=1.44\cdot 10^4$ cm^{-1} for light with $\lambda=6328$ Å. But in the experiment, the most intense scattering is observed on magnons with wave vectors $k<k_1$ (Fig. 3a).

We turn to scattering by quasiparticles with $\theta_k'\approx 0$ in magnetic fields $H_0\neq H_{0c}$. As has already been mentioned in Section 3, these quasiparticles correspond to the lower limit of the spectrum of spin waves, independently of H_0. According to the results of the measurements of the angular distribution of the scattering intensity at $\theta_k'=0$ (Fig. 3b), the values of the wave vectors of the scattering quasiparticles are localized near two values: $k_1\approx 1.4\cdot 10^4$ cm^{-1} and $k_2\approx 2.0\cdot 10^4$ cm^{-1}. This is characteristic of the scattering both in fields $H_0<H_{0c}$ and in fields $H_0>H_{0c}$. It is not difficult to explain the observed peculiarity, if one takes into account the discreteness of the x component of the wave vectors of the excited quasiparticles, which occurs because of the influence of the specimen boundaries. For example, for volume magnons [see expression (2)] the condition $k_xd=n\pi$ must be satisfied, where n is an integer. It is now easy to show that for a specimen with $d=30$ mm, only the wave vectors $\mathbf{k}_1$ and $\mathbf{k}_2$ satisfy the Bragg conditions, with $n=1$ and $n=2$ respectively (see Fig. 8b). The maximum corresponding to $n=3$ lies outside the bounds of observable **k**.

Figure 8a shows sections of the lower bounds of the spectrum of volume spin waves at fields corresponding to scattering maxima for $H_0<H_{0c}$ (see Fig. 2a). Here the points denote experimental values obtained from the parameters of the scattered light. From Fig. 3b and Fig. 8a it is evident that the most intense scattering occurs near the points of intersection of the dispersion curves corresponding to spin waves and to longitudinal acoustic waves. The points themselves that correspond to maximum intensity of the scattered light are also marked in Fig. 8a. Thus it is natural to suppose that what was observed experimentally was excitation of magnetoelastic oscillations.

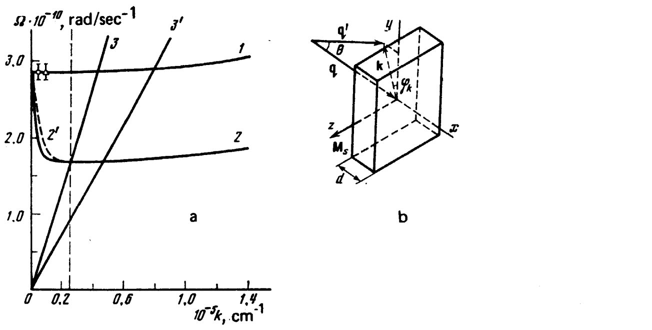

FIG. 7. a) Spin-wave spectrum in a plate of yttrium iron garnet of thickness $d=30$ μm at $H_0\approx H_{0c}=1050$ Oe: 1) $\theta_k'=90°$; 2) $\theta_k'=0$, $n=1$; 2′) $\theta_k'=0$, $n=2$; 3 and 3′) the straight lines for elastic waves (longitudinal and transverse, respectively). The points denote experimental values corresponding to the maxima of Curves 1 and 2 of Fig. 3a and to the spectrum of Fig. 4a. b) The coordinate system adopted, and illustration for light scattering by quasiparticles with $\theta_k'=90°$.

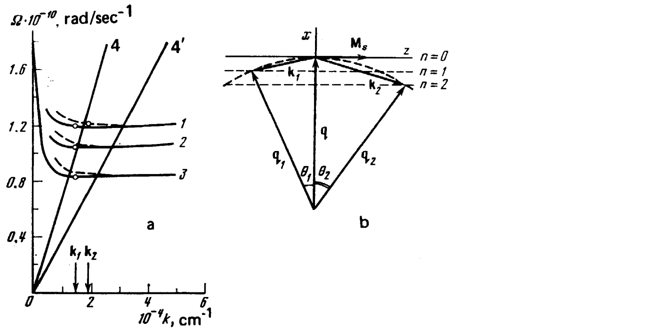

FIG. 8. a) Lower bounds of spin-wave spectrum ($\theta_k'=0$) in a thin plate of YIG at various values of H_0: 1) $H_0=758$ Oe; 2) $H_0=675$ Oe; 3) $H_0=549$ Oe; 4 and 4′) the straight lines for elastic waves. The points denote experimental values corresponding to the scattering maxima at $\theta_k'\approx 0$ (Fig. 3b) and to spectra of the type represented in Fig. 4b. b) Geometry of light scattering by quasiparticles with $\theta_k'=0$.

We shall discuss in more detail the nature of the quasiparticles with $\theta_k' \approx 0$, since they are somewhat unusual. As has already been mentioned, such quasiparticles cannot be excited directly by the external alternating magnetic field, since their frequency (especially at small H_0) is considerably smaller than half the pumping frequency. We postulate the following mechanism for origin of the oscillations with $\theta_k' = 0$ observed in the experiment. Initially, the external alternating magnetic field excites standing spin waves (see Section 1) with $\theta_k' = \theta_k = 90°$ and frequency $\Omega_k = \Omega_0/2$, and also spin waves coupled to the parametric through two-magnon and four-magnon interactions. These secondary spin waves are degenerate in frequency with the parametric waves but have $\theta_k \neq 90°$.[14] Then the standing waves with frequency $\Omega_k = \Omega_0/2$ relax by disintegration into two new waves with frequencies $\Omega_{k1} = \Omega_k\ (H_0, \theta_k' = 0)$ and $\Omega_{k2} = \Omega_0/2 - \Omega_{k1}$. In fields $H_0 < H_{0c}$, the frequency Ω_{k2} falls within the spin-wave spectrum. But in fields $H_0 > H_{0c}$, this frequency is far below the minimum frequency of spin waves; that is, Ω_{k2} corresponds to oscillations having a gapless spectrum. In our case it is elastic oscillations that have such a spectrum.

We emphasize that this process of disintegration can occur only in a system of standing waves. In the contrary case, it does not satisfy the condition of conservation of the vector **k** for interacting oscillations.

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