HARD EXCITATION OF MAGNONS IN PARALLEL PUMPING IN AN ANTIFERROMAGNETIC SUBSTANCE

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A discontinuous production and disappearance (with "hysteresis") of a magnon excited state is observed in an investigation of parallel pumping at a frequency $\omega_p = 22 \times 10^{10}\ \mathrm{sec}^{-1}$ in $MnCO_3$ (T = 1.6° K) under continuous conditions. The explanation proposed assumes four particle interaction of magnons belonging to the isoenergy surface $\omega_{1k} = \omega_p/2$.

INVESTIGATIONS of parametric excitations of spin waves (magnons) in antiferromagnets (AF) by the method of parallel pumping were initiated relatively recently[1-3]. As a rule, a pulse[1-3] or quasipulse[3,4] procedure is used in this method. It seemed natural that the use of a continuously acting microwave field on the sample would permit observation of details of this phenomenon.

The investigated object was the easy-plane antiferromagnet $MnCO_3$. The source of the microwave energy of frequency ν_r = 35 GHz was a klystron rated ~ 10 mW. A single-crystal $MnCO_3$ plate measuring about 1.5 × 1.5 × 0.5 mm was placed in a flow-through cylindrical resonator with Q ≈ 4000 (TE_{012} mode), which was filled with superfluid liquid helium (T = 1.6° K). The microwave field **h** and the constant magnetic field $\mathbf{H}_0$ were parallel to each other in the basal ("easy") plane of the crystal.

Figures 1a and 2 show examples of the experimental plots of the power transmitted through the resonator as a function of the external magnetic field (at a constant input power, Fig. 1a) and of the input power (at a constant external field, Fig. 2).

We call attention to the following details.

1) The smallest excitation threshold of the magnon pairs takes place at H_0 close to H_c, i.e., as $\mathbf{k} \to 0$ (curves 2 and 3 in Fig. 1a). This agrees with the predictions of the simplest theory[5a]:

$$\gamma h_c = 2\eta_{1k}\omega_p/\gamma(2H_0 + H_D), \qquad (1)$$

if one does not assume an anomalous dependence of the relaxation frequencies $\eta_{1k} \equiv \Delta\omega_{1k}/2$ of the magnons ω_{1k} on k.

2) Measurements made at a small excess of pump power over the minimum threshold reveal, just as in[4], a phonon hump on the $h_e(H_0) \approx H_q(H_0) \approx h_c(H_0)$ curves (see Fig. 1b). The width of the hump is appreciable. It must therefore be analyzed with allowance for the multiplicity of the intersection points of the phonon and magnon spectra in $MnCO_3$, where the limiting magnon velocities are different for different k[6].

3) The slight deviation of the extreme right section of the $h_c(H_0)$ curve from vertical can be easily attributed to the small influence of the dipole-dipole interaction on the magnon spectrum[5b] and the coupling of the magnons with the pump. The deviation of the $h_e(H_0)$ and

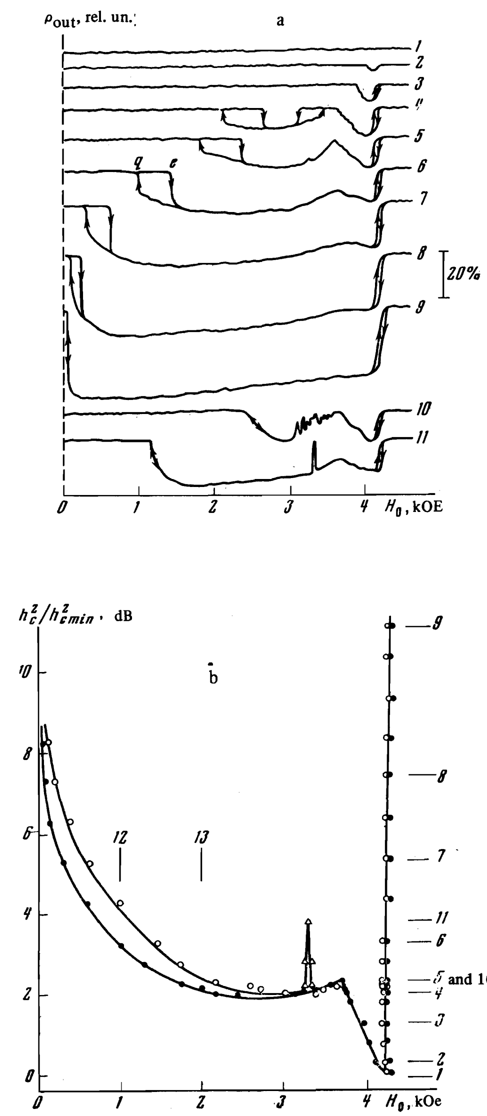

FIG. 1. Parallel pumping in $MnCO_3$ at T = 1.6°K, $\mathbf{h} \parallel \mathbf{H}_0 \perp C_3$. a—Some of the plots of the power transmitted through the resonator as a function of H_0 (at specified values of the input power). 1–9—continuous klystron generation; 10, 11—meander regime. b—Squares of relative excitation amplitudes h_e (○) and quenching amplitudes h_q (●) vs H_0. Δ—points obtained in the meander regime. Sections 1–11 correspond to Fig. 1a, and 12 and 13 to Fig. 2.

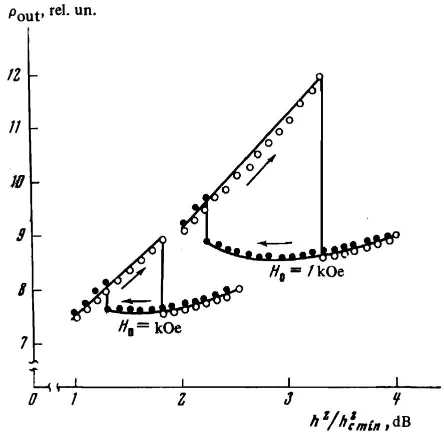

FIG. 2. Sample plots of the transmitted power against the power at the resonator input at fixed H_0. (All the powers were measured relative to the minimum threshold value, $h_{c\ min} \approx 0.1$ Oe). The designations of the points are the same as in Fig. 1b.

$H_q(H_0)$ curves from near-hyperbolic (see formula (1)) in the region of small $H_0 < 50$ Oe is connected with the appearance of a domain structure.

4) The "H_1" peak (see Fig. 1 of[4a]) does not appear distinctly enough on any of the transmitted-power curves of Fig. 1, which were obtained in the continuous regime. One probable reason is that the width of the hysteresis with respect to H_0, which occurs when the excited state sets in and vanishes (see below), exceeds the width of the peak. Another reason may be the inevitable variation of the pump power and of the external field. To detect the corresponding peak on the $h_c(H_0)$ curve, we have obtained a number of plots (of the type 10 and 11 in Fig. 1a) of the transmitted power against H_0 with a meander modulation of the klystron frequency. Attention is called to the presence of a fine structure at small excesses of the power above the minimum threshold power.

5) Greatest interest attaches to the clearly jump-like ("hard") character of the appearance and disappearance of the parametric magnons, observed in a wide interval of constant fields far from H_c (Figs. 1 and 2). A similar phenomenon was observed earlier in YIG in[7]. It is also obvious that the corresponding values of the field at a given amplitude at the resonator input (Fig. 1) do not coincide, nor do the excitation and quenching amplitudes h_e and h_q at constant H_0 (Fig. 2). Hysteresis may be caused by heating of the sample (see, e.g.,[8]) and by a change of the real part of the susceptibility χ' at $h > h_c$, but in such cases the hysteresis loop would have the opposite shape, such as at $H_0 \approx H_c$ in Fig. 1.

The jumplike onset of the excited state in the case of parallel pumping in AF can be observed also in a pulsed regime. This follows, in particular, from the oscillogram given in[4b], and was noted by A. S. Borovik-Romanov (private communication).

The "hard" excitation and quenching of parametric magnon pairs may be due to definite physical mechanisms. One of them may be the following. In easy-plane antiferromagnets, owing to the weak influence of the magnon field, the coupling with the pump is practically the same for all pairs of potentially unstable magnons. The wave vectors **k** of the latter fill in k-space a certain layer of small thickness $\sim \eta_{1\mathbf{k}}/|\nabla_{\mathbf{k}}\omega_{1\mathbf{k}}|$ near the equal-energy surface S described by the equation $\omega_{1\mathbf{k}} = \omega_r/2$ (this is an ellipsoid of revolution for $MnCO_3$[6]). Among the magnon-magnon relaxation channels, there is one in which not only the "trial" magnon $\omega_{1\kappa}$ but also the "mate" $\omega_{1,-\kappa}$ vanishes from the surface S_ω and a pair $\omega_{1\mathbf{k}} + \omega_{1,-\mathbf{k}}$ is produced, with **k** also on S_ω. These processes are described by the same total-Hamiltonian component which gives the "pump renormalization" proposed in[9]. Their contribution $\Delta\eta_{1\mathbf{k}}$ to $\eta_{1\mathbf{k}}$ vanishes if the occupation numbers $n_{1\mathbf{k}}$ have a uniform distribution over S_ω. The "soft" excitation of the magnon pairs on S_ω is delayed because of this relaxation channel. The growth of h at constant H_0 (or, equivalently, the change of H_0, corresponding to the $h_c(H_0)$ curve, at constant h) leads only to "heating" of S_ω until all the magnons of this surface are excited jumpwise (since $\Delta\eta_{1\mathbf{k}}$ vanishes in this case). Similar arguments can be advanced for a qualitative explanation of the "hard" quenching of the magnon pairs. One need only recognize that in this case at $h_q < h < h_e$ the considered four-magnon processes maintain the amplitude of the "trial" magnon and its "mate" by pumping from all pairs of the surface S_ω. The proposed mechanism leads naturally to a dependence of the width of the hysteresis with respect to h on H_0 (see Fig. 2), since the relative value of the contribution of the paired four-magnon interaction to the relaxation frequency $\eta_{1\mathbf{k}}$ depends on the surface area S_ω.

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