OBSERVATION OF THE PROPAGATION OF SPIN WAVES IN ANTIFERROMAGNETS

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Pairs of electron and nuclear spin waves were excited on the end face of single-crystal antiferromagnetic $CsMnF_3$. Propagation of electron spin waves along the sample, over a length $\sim$ 3 mm, was observed. The lifetime of the propagating spin waves is estimated at $\tau_0 \sim 2$ μsec.

It was recently observed that under certain conditions it is possible to excite parametrically in antiferromagnets magnons of the electron (e) and nuclear (n) spin systems by means of an external microwave field [1 - 3]. Depending on the excitation condition, one microwave photon (p) decays in this case into a pair of magnons, with energy and quasimomentum conservation, in three different combinations: e + e, e + n, and n + n. This method can be used to excite e-magnons with wave vector $\vec{k}$ from 0 to $\sim 10^6$ cm^{-1}. It follows from the results of [4] that the relaxation rate $\Delta\nu$ of the e-magnons in the easy-plane antiferromagnet $CsMnF_3$ decreases rapidly with decreasing temperature, and amounts to $\sim$ 0.1 MHz at T = 1.2°K. The mean free path corresponding to a lifetime $\tau = 1/2\pi\Delta\nu \sim 1$ μsec and to a propagation velocity $v = \partial\omega/\partial\vec{k} \sim 10^5$ cm/sec at $\vec{k} \sim 10^5$ cm^{-1} is relatively large ($\sim$ 1 mm). We have therefore deemed it of interest and possible to observe experimentally the propagation of e-magnons with wave vector $\vec{k} \sim 10^5$

cm^{-1} through a sample.

From the point of view of the method, the experiment can be divided into two parts: excitation of the magnons on one end, and registration of their appearance on the other end of a sufficiently long sample.

The first part entails no difficulty at present and is easily effected by using parametric excitation. As to the second part, we note immediately that the most direct method that suggests itself, the detection of the magnons by their microwave radiation, entails certain difficulties, since magnons with a wave vector $\vec{k} \sim 10^5$ cm^{-1} hardly interact with an electromagnetic field. The registration method used by us is based on a previously observed effect of hard excitation of e-magnons in antiferromagnets, which is apparently the result of the lowering of the parametric-excitation threshold when the number of magnons n_k is increased [5].

We used in the experiments a setup consisting of two microwave spectrometers. The resonator cells, which were high-Q cylindrical cavities operating in the H_{011} mode, had a common bottom of 2.5 mm thickness, through which a hole of 2 mm diameter was drilled (Fig. 1). A single-crystal sample of cylindrical shape, ∿ 5 mm long and ∿ 2 mm in diameter, was glued in the hole with BF-4 adhesive in such a way that it projected equally into both cavities. The principal axis of the sample coincided with the axis of the cylinder. The cavities were so placed that the sample was located in an antinode of the microwave magnetic field in each cavity, and the field in each cavity was parallel to the external static field and was in the basal plane of the sample. In all other respects, the spectrometers were similar to those described in detail in [6].

The experiments were performed at a temperature T = 1.2°K. To decouple the cavities at the microwave frequency, we used the fact that identical e-magnons can be exicted at different pump frequencies in $p \to e + n$ and $p \to e + e$ processes.

The energy conservation law leads to the following respective frequencies in these processes:

$$\nu_p = \nu_k^e + \nu_k^n, \quad (1)$$

$$\nu_p = 2\nu_k^e, \quad (2)$$

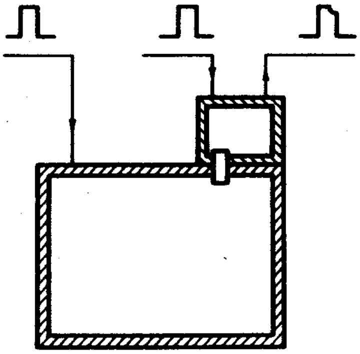

Fig. 1

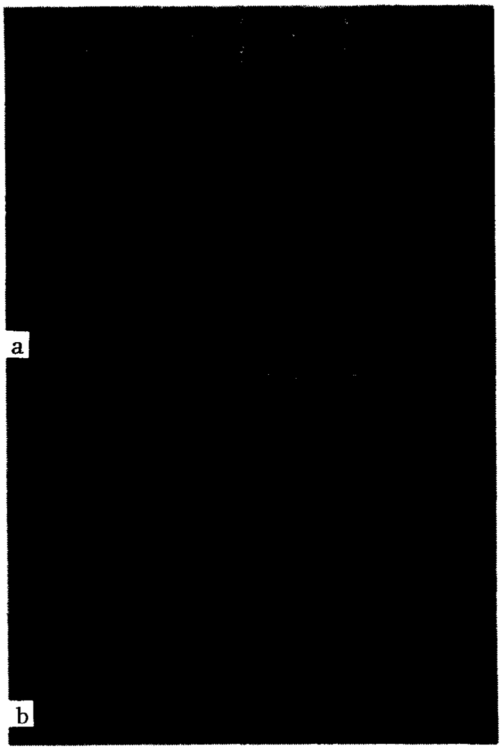

Fig. 2

Fig. 1. Schematic diagram of the cavity cells of the microwave spectrometers.

Fig. 2. Oscillograms of microwave pulses passing through the cavities at different delays τ. First pulse — ν_{1p}. Sweep — 50 μsec/cm.

where

$$\nu_k^n = \nu_k^\circ \left(1 - \frac{\gamma^2 H_\Delta^2}{(\nu_k^e)^2}\right)^{1/2}; \quad \nu_k^\circ = 0.666 \text{ GHz } [7]$$

is the unshifted nuclear frequency of the Mn^{++} ions $H_\Delta^2 = (6.4/T)$ kOe^2 [8] is the gap in the electron spin-wave spectrum and is due to the hyperfine interaction, and $\gamma = 2.8$ GHz/kOe is the gyromagnetic ratio (the values of the constants are indicated for $CsMnF_3$).

A rectangular microwave pulse P_1 of frequency $\nu_{1p} = 9.47$ GHz was applied to the exciting cavity, in which, according to (1), e-magnons were generated with frequency $\nu_k^e = 9.00$ GHz. The maximum pulse power P_{1max} attained in the experiments exceeded the threshold power of the p → n + e process by ∿ 15 dB.

At an instant τ after the end of the pulse P_1, a rectangular microwave pulse P_2 was applied to the receiving cavity, at a frequency $\nu_{2p} \simeq 2\nu_k = 18.00$ GHz and at a power close to the threshold power of the p → e + e process. Owing to the large frequency difference, no penetration of the microwave power from the exciting cavity into the receiving cavity was observed. If the power in the second cavity exceeds the threshold value, then a "chink" appears on the pulse passing through the cavity, at a time t from the start of the pulse, and corresponds to hard excitation of the spin waves. In the absence of the signal P_1, the time t, given H, T, and ω, is determined only by the ratio P_2/P_{2c} of the power to the threshold value.

When the power of the pulse P_1 exceeds the threshold power of the p → n + e process the time t starts to decrease with increasing power and with decreasing time interval τ between the pulses. The maximum delay τ at which a change of t was observed at $P_1 = P_{1max}$ was ∿ 15 μsec.

Figure 2 shows, by way of the example, oscillograms of the pulses passing through the cavities at different delay times τ ($\nu_{2p} = 17.9$ GHz, H = 1.3 kOe). The results of the described experiments offer evidence of the propagation of e-magnons through the sample, and that this propagation increases the number of magnons n_k in the part of the sample situated in the receiving cavity. This lowers the threshold power P_{2c} and shortens the time.

Starting from the dependence of the time t of the "chink" to the delay time τ at a constant power, we were able to determine the lifetime of the traveling e-magnons, namely $\tau \approx 2$ μsec; this is close to the value obtained in [4].

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