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PARAMETRIC EXCITATION OF SPIN WAVES IN ANTIFERROMAGNETIC $CsMnF_3$

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We describe in this article the results of observation of excitation of electron spin waves in an antiferromagnet when the static and microwave magnetic fields are parallel.

The investigations were made on $CsMnF_3$. The low-frequency branch of the AFMR spectrum in $CsMnF_3$ is described by the formula [1, 2]

$$(\nu/\gamma)^2 = H^2 + 2H_E H_{AT} . \qquad (1)$$

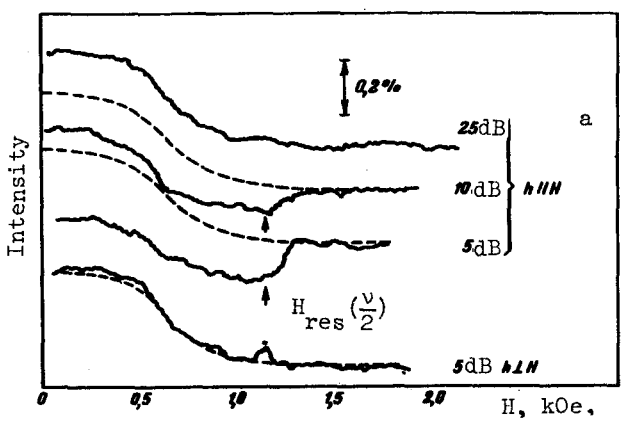
The second term in this formula is due to the hyperfine interaction. According to the data of Lee, Portis, and Witt [1] H_E = 350 kOE and H_{AT} = 9.15/T Oe.

We investigated the dependence of the absorption of the microwave power in the sample on the magnitude of the external magnetic field. The investigations were made at 9.43 GHz with a pulsed source (τ = 1 μsec) and at 36 GHz with a continuous source. The sample was placed in a high-Q resonator such that the static magnetic field (H) and the microwave magnetic field (h) were in the basal plane of the crystal.

It was observed that when h and H are parallel, starting with a certain value of the microwave power, absorption in the sample sets in at field values below a definite limit H_1. Within the limits of measurement accuracy, the field value H_1 does not depend on the power. Figures 1a and 1b show several curves characterizing the observed absorption at different power levels. The lower curve of Fig. 1a was obtained at high power, but unlike the other curves, with h perpendicular to H. The observed sharp absorption peak at a magnetic field value corresponding to ordinary AFMR can be explained, in accordance with (1), as being due to insufficient parallelism of the fields.

The absorption at 9.4 GHz is very small, practically the same for all fields lower than H_1, and increases continuously with increasing power. At 36 GHz the absorption is much more pronounced. It is seen from Fig. 1b that at a slight excess of power above threshold, the absorption is not observed at all fields lower than H_1. The range of the fields expands with increasing power. At the field value H_1, the absorption vanishes jumpwise. For a fixed value of the magnetic field, the absorption increases sharply with increasing power, passes through a maximum, and then starts to decrease, as seen from Fig. 2. Estimates of the value of the threshold microwave fields h_c yield $h_c \sim 2$ Oe and $h_c \sim 0.5$ Oe for experiments at 9.4 and 36 GHz, respectively.

We propose that the observed absorption is due to parametric excitation of spin waves



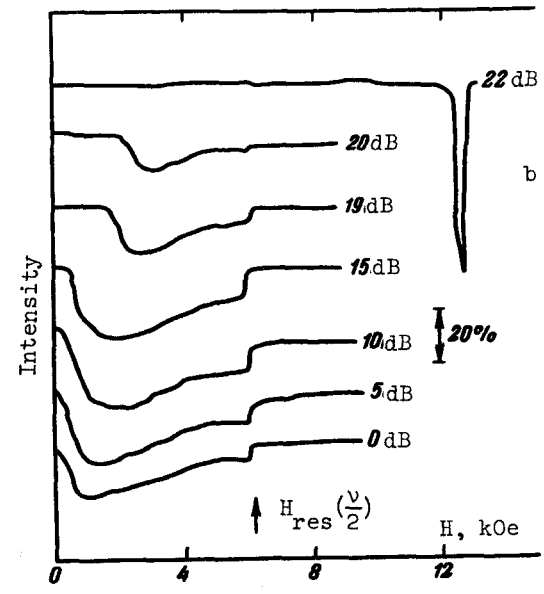


Fig. 1. Plot of transmitted microwave intensity. Numbers to the right of the curves - readings of regulating attenuator. At zero dB, the microwave field in the sample is equal to h_{max}: a - ν_1 = 0.93 GHz, T = 4.2°K, h_{max} = 30 Oe; dashed curve - plot corresponding to 25 dB and h H; b - ν_2 = 36 GHz, T = 2.0°K, h_{max} ∿ 10 Oe.

with frequency equal to half the exciting frequency, in analogy with the situation in ferrites (cf., e.g., [3]). Two facts favor this explanation. First, the vanishing of absorption following a 90° rotation of the static magnetic field relative to the microwave field. Second, the equality of the upper limit of magnetic field at which the absorption is observed to the value of the resonant AFMR field, as calculated from formula (1), at half the excitation frequency. The resonant field values calculated for the corresponding frequencies and temperatures are designated in Figs. 1 and 2 by an arrow with a label $H_{res}(\nu/2)$.

The essential distinguishing features of parametric excitation of spin waves in antiferromagnets are the following: At small values of k the energy of the spin waves of antiferromagnets depends little on the direction of their wave vector $\vec{k}$ relative to the direction of the applied field. The relative energy change does not exceed $4\pi\kappa$ [4] (κ is the volume susceptibility), i.e., about 1% according to [1]. Therefore, at any excess of power above threshold and at fixed values of the exciting frequency ν_{exc} and of the external magnetic field H, spin waves will be excited with values of k that are equal within the limits of the indicated accuracy; these values of k are determined from the spin-wave dispersion law:

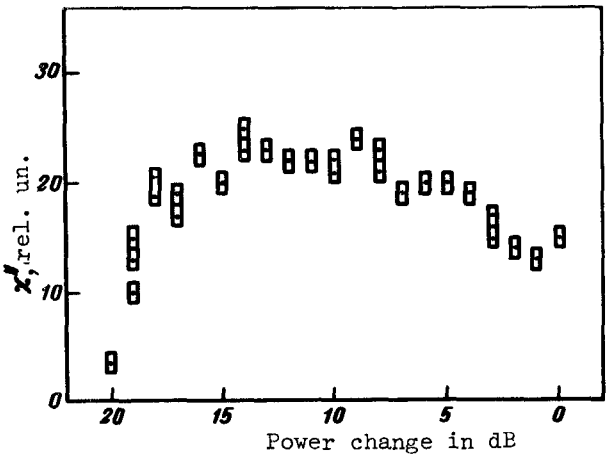


Fig. 2. Relative absorption vs. exciting microwave power. ν = 36 GHz, T = 2.0°K, H = 2.5 kOe.

$$\left(\frac{1}{2}h\nu_{exc}\right)^2 = (h\nu_k)^2 = (h\nu_0)^2 + \theta^2(ak)^2. \quad (2)$$

Here ν_0 is calculated from formula (1) (θ is

the exchange constant and a is the lattice constant). Taking as a very rough estimate $\theta \sim H_E$, we find that in the experiments at 9.4 GHz the largest values of $q = ak$ for the excited spin waves are $q_{max} \sim 3 \times 10^{-3}$. For 36 GHz we get $q_{max} \sim 2 \times 10^{-2}$. It should be noted that at $q \sim 10^{-2}$ an important role can already be assumed by the anisotropy of the exchange interaction [2].

However, the smallness of the dipole interaction of the spin waves in an antiferromagnetic raises difficulties when it comes to explaining theoretically the relatively low threshold of the parametric resonance observed by us. In particular, it follows from Ozhogin's calculations [4] that, in the first approximation, parametric excitation of AFMR and spin waves is possible only in the presence of weak ferromagnetism.

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Addendum. After submitting this article, we became acquainted with a paper by Seavey [5], who observed parametric excitation of the electron spin waves in $CsMnF_3$ at 17.5 GHz.

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MAGNETORELATIVISTIC MODEL OF A PULSAR PULSE

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The pulsed character of pulsar radiation is usually connected (this being the most probable explanation) with the existence of a definite directivity of their radiation pattern, which can be either "pencil-like" or "knife-like." It is the rotation of this diagram in space which determines the observed radiation in the form of individual pulses. In the heretofore proposed models, the directivity of the radiation pattern is attributed to geometric factors, viz., detachment of plasma clouds in the equatorial plane of the part of the magnetosphere of a neutron star rotating with relativistic velocity [1], a special distribution of the radiating particles in "convenient" parts of the magnetosphere [2], etc. It has been impossible to date, however, to obtain from physical considerations quantitative estimates of the aperture $\Delta\nu$ of the directivity pattern. On the other hand, it is well known that the directivity is an invariant property of relativistic objects.

In this connection, we can propose the following model of a pulsar.

1. Assume that the pulsar is a neutron star with a dipole (or more complicated) magnetic field, rotating or oscillating in such a way that the pulsar surface regions containing the magnetic fields move with relativistic velocities. We are unable to justify such a model rigorously at present, but we can advance some qualitative considerations in