Microwave energy absorption by thermal magnons in the layered antiferromagnet $BaMnF_4$

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An absorption effect linear in the power was observed at frequencies 75–80 GHz in a range of magnetic fields where magnons exist with a frequency equal to half the pump power frequency; this effect increases when the sample is heated and when the pump frequency approaches the ferromagnetic resonance of the high-frequency branch.

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It follows from static[2,3] and high-frequency investigations that the rhombic crystal $BaMnF_4$ is a two-dimensional antiferromagnet at temperatures $T < T_N = 25\,°K$, namely, the exchange interaction between ions in one layer is much larger than between ions of different layers, and antiferromagnetic order is established in the layer. The antiferromagnetic resonance (AFMR) was investigated in[3]. Both AFMR branches were investigated, it was shown that the field dependence of the resonance frequency satisfies the theoretical formulas for rhombic antiferromagnets, and the temperature dependence of the gaps in the AFMR spectrum was investigated.

In this study we have observed nonresonant absorption of microwave power in $BaMnF_4$ when the high-frequency field **h** is parallel to the static magnetic field **H** ($\mathbf{h} \parallel \mathbf{H}$). This effect in linear in the microwave power and has an appreciable value at pump frequencies ν_p close to the resonance frequency of branch II (AFMR-II), namely $\chi'' \approx 0.1$ cgs emu/cm^3, i.e., it is comparable with the absorption in the case of AFMR.

The investigations were performed with a direct-amplification spectrometer,[4] and a short-circuited end of a waveguide served as the absorbing cell. The reflected power was plotted with an x–y recorder as a function of the static magnetic field.

The $BaMnF_4$ sample at our disposal consisted of two single-crystal blocks of approximately equal volume. The blocks were so arranged that their easy-antiferromagnetism axes (the b axes) were inclined ~5 and 20° to the constant magnetic field. Figure 1 shows the AFMR spectra at $T = 4.2\,°K$ for the first and second blocks; the experimental points coincide with the theoretical plots calculated from the results of[3]. Figure 2 shows the absorption curves for $\nu_p = 73.7$ GHz and $\mathbf{h} \parallel \mathbf{H}$ at various temperatures. In addition to the AFMR-I branch (narrow peak) one can clearly see the microwave-power absorption in the field region $H_{f1} < H < H_1$, where H_{f1} is the sublattice-flipping field.

The effect increases with rising temperature, as well as when ν_p approaches the AFMR-II frequency. At temperatures above 6 °K the two factors act simultaneously, since the AFMR-II frequency begins to drop with rising temperature

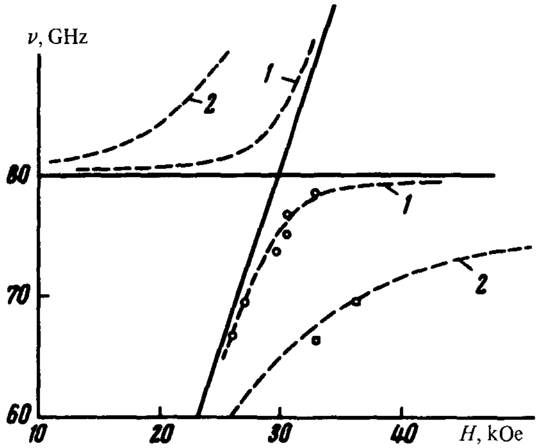

FIG. 1. AFMR spectrum for a sample consisting of two blocks.

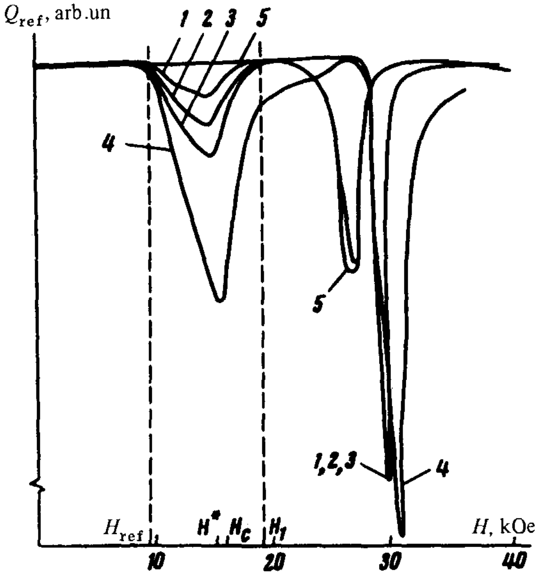

FIG. 2. Plot of absorption line: 1) $T = 2.04$ °K; 2) $T = 3.47$ °K; 3) $T = 4.2$ °K; 4) $T = 7.1$ °K; 5) $T = 20$ °K.

and approaches ν_p.[3] The lines 1, 2, 3, and 4 were obtained at temperatures at which ν_p was lower than the AFMR-II frequency, and line 5 with ν_p higher.

Since the observed effect appears only at **h** ∥ **H** and increases with temperature, we assume that it is caused by absorption of the microwave power by the thermal spin waves connected with the pump field, just as in parametric excitation of the spin waves by the parallel-pumping method. However, the parametric-excitation threshold was not reached in our experiments, for otherwise the effect would not be linear in the power. The subthreshold absorption (STA) does not lead to an experimental increase of the number of spin waves, since the energy influx from the pump does not exceed the dissipation in the spin-wave system, and the microwave power is diverted to the lattice via the pool of thermal magnons. This type of absorption should vanish in magnetic fields in which the parametric-resonance condition $\nu_k = \nu_p/2$ cannot be satisfied (ν_k is the frequency of magnons with wave vector **k**). The boundary H_c of the region of the magnetic fields, where this condition is satisfied is usually calculated from the field dependence of the homogeneous-resonance frequency, $\nu_0(H_c) = \nu_p/2$. However, as shown in[5], dipole interaction leads to a difference $\sim \nu_0 4\pi\chi_0$ between the inhomogeneous resonance frequency and the pure homogeneous resonance frequency as $\mathbf{k} \rightarrow 0$. The exact calculation was performed for crystal symmetry types other than that of $BaMnF_4$.

Using the result of the calculation[5] for a crystal with magnetic anisotropy of the "easy axis" type, one can expect H_c to be ~ 1 kOe smaller than H_1 under the conditions of our experiment, if the main contribution to the STA is made by spin waves with $\mathbf{k} \parallel \mathbf{H}$. The experimental value is $H_1 - H_c = 2.5$ kOe. The values of H_c for the two blocks differ by 0.5 kOe, and Fig. 2 shows their mean value.

Figure 3 shows the temperature dependence of the power Q absorbed in the observed effect. Curve 1 is drawn through the experimental points. We used only those lines where the power absorbed on account of the AFMR is much less than the STA. Curve 2 is a plot of a quantity proportional to the number of thermal magnons with frequency $\nu_k = \nu_p/2 = 37$ GHz, calculated with the aid of the Bose distribution $n_B(T)$, while curve 3 represents the amplitude A_2 of the AFMR-II oscillations (the AFMR-II half-width is known from[3]).

The agreement of the plots of $Q(T)$ and $n_B(T)$ at $T < 6$ °K confirms our assumption that this absorption is indeed due to thermal magnons with frequency $\nu_p/2$.

The increase of the effect when the frequency approaches that of AFMR-II indicates that the coupling of the thermal short-wave magnons with the practically-homogeneous pump field proceeds via homogeneous AFMR-II oscillations, as predicted by the theory of parallel pumping in antiferromagnets.[6] This observation serves as direct proof of such a parametric-coupling mechanism.

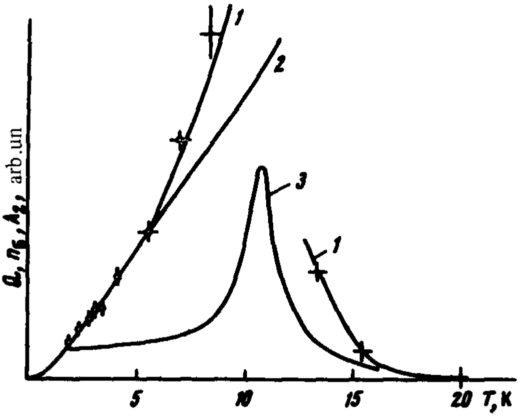

FIG. 3. Temperature dependence of the subthreshold-absorption amplitude.

Kaganov and Tsukernik[7] have investigated theoretically the STA phenomenon in a ferromagnet. The effect predicted by them is smaller by 4—5 orders of magnitude than that observed by us.

A similar absorption, but much smaller in magnitude, was observed in[8,9]. The effect in a three-dimensional ferromagnet[8] is extremely small ($\chi'' \sim 10^{-4}$). A more appreciable STA effect was observed in the two-dimensional ferromagnet K_2CuF_4 in[9] ($\chi'' \approx 0.1$ cgs emu/cm^3). This effect, which is gigantic in comparison with the prediction of[7], is apparently the result of two circumstances:

1. A characteristic feature of antiferromagnets is that the parametric coupling between the microwave field and the magnons is via oscillations of the high-frequency branch of the spectrum.[6] Our experiments were performed at frequencies close to the frequency of the AFMR-II branch, and therefore, this coupling was particularly large.

2. The magnetic two-dimensionality of $BaMnF_4$ causes the energy of the magnons propagating across the antiferromagnetic layers (under the conditions of our experiment these are the magnons with $\mathbf{k} \parallel b \parallel \mathbf{H}$) to depend very little on the wave vector (quasimomentum) and therefore, the microwave spin-wave density of states is much higher than in the three-dimensional case.

The relatively small value of the STA at $T > 10$ °K is apparently due to the fact that the spin-wave approach does not apply at high temperatures (the Néel temperature of $BaMnF_4$ is ~ 25 °K).

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