Nature of hard parametric excitation of nuclear spin waves in antiferromagnetic $CsMnF_3$

A. V. Andrienko
I. V. Kurchatov Institute of Atomic Energy, 123182, Moscow

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A modulation method has been used to measure the relaxation rates of nuclear magnons corresponding to the thresholds for the appearance (h_{c_1}) and disappearance (h_{c_2}) of paramagnetic magnons. The peak at the threshold h_{c_1} at a pump frequency $\nu_p \simeq 780$ MHz results from a resonant absorption of magnon energy by defects having a transition frequency $\nu_d \simeq 390$ MHz. The hard excitation occurs because this relaxation mechanism comes into play upon saturation of transitions with the frequency $\nu_p/2$.

A study of the antiferromagnet $CsMnF_3$ has revealed that the parametric excitation of nuclear spin waves is a hard process.[1] The explanation for this hard process lies in the existence of two threshold fields, h_{c1} and h_{c2} ($h_{c1} > h_{c2}$). The first corresponds to the appearance of paramagnetic nuclear spin waves, and the second to the disappearance of these waves. Studies[2] of the hardness parameter $\zeta = (h_{c1}/h_{c2}) - 1$ have shown that the plot of ζ versus the pump frequency ν_p is clearly of a resonant nature. The position of the peak is independent of the temperature and the magnetic field. The hardness can be explained on the basis that either the coupling coefficient (V) showing the coupling with the pump field or the relaxation rate (Γ) of the nuclear spin waves depends on the number of these waves. In the latter case, it would be sufficient to assume that, as the number of parametric nuclear spin waves increases, some mechanism for their relaxation reaches saturation, and the rate Γ decreases. The physical parameter which characterizes the hardness is not ζ but the part of the relaxation which turns off, $\Delta\Gamma = (h_{c1} - h_{c2})V$.

In the present experiments, nuclear spin waves were excited by a parallel microwave pump with a frequency $\nu_p = 650$–950 MHz. These waves were detected on the basis of the "modulational-response" signal of the sample.[1]

We first studied the effect of a field $H_m \cos \omega_m t$, which modulated the wave spectrum, on the thresholds h_{c1} and h_{c2}. Under the conditions ($\vec{H}_m \| \vec{H}$, $\nu_p \gg \nu_m > 2\Gamma$, and $h_c/h_{c0} - 1) \ll 1$, this effect is described by[3,4]

$$h_c/h_{c0} - 1 = 4V^2 H_m^2 [\nu_m^2 + 4\Gamma^2]^{-1}.$$

Here h_{c0} is the threshold field in the absence of a modulation, and h_c is that in the case with a modulation. By studying the effect of a modulation on the thresholds h_{c1} and h_{c2}, we can determine the values of V and Γ corresponding to the two thresholds. The peak on the plot of $(h_c/h_{c0} - 1)$ versus ν_m is observed[4] at $\nu_m \sim 2\Gamma$, so we can estimate the values of Γ corresponding to the two pump thresholds without going through a detailed study of the entire curve.

The experiments showed that H_m has different effects on the thresholds h_{c1} and h_{c2}, and that the difference becomes progressively more obvious as ζ is increased. The coefficients V measured for the two thresholds by this method agree within the experimental error, but there is a pronounced difference in the relaxation rates $\Gamma_1 = h_{c1}V$ and $\Gamma_2 = h_{c2}V$. Figure 1 shows experimental results on the relative increase in the thresholds h_{c1} and h_{c2} under very hard conditions. The huge differences in the effects of the modulation on the thresholds h_{c1} and h_{c2} and in the positions of the peaks correspond to the relaxation rates calculated from the two threshold fields, h_{c10} and h_{c20}: $\Gamma_1 = 60 \pm 15$ kHz and $\Gamma_2 = 9 \pm 2.2$ kHz. The hardness thus results from a decrease in the relaxation rate of the nuclear magnons during their parametric excitation. The changes in the hardness parameters from sample to sample suggest that this component of the damping is a consequence of an interaction of the nuclear spin waves with defects.

We then studied the frequency dependence, the field dependence, and the temperature dependence of the part of the relaxation of the nuclear spin waves which turns off. Figure 2 shows the frequency dependence of $\Delta\Gamma$ for one of the $CsMnF_3$ samples, at a fixed value of H. According to the model under consideration here, the width of the peaks on the plot of $\Delta\Gamma(T)$ may correspond to the relaxation rate of defects or to their frequency distribution. Figure 3 shows the temperature dependence of $\Delta\Gamma$ at the hardness maximum. As the temperature is raised, the part of the relaxation which turns off initially increases; it later passes through a maximum at $T \simeq 3.5$ K. The quantity $\Delta\Gamma$ depends only weakly on the magnetic field.

If we assume that the component $\Delta\Gamma$ stems from a resonant absorption of nuclear spin waves by defects with a frequency ν_d, we could attempt to turn this relaxation

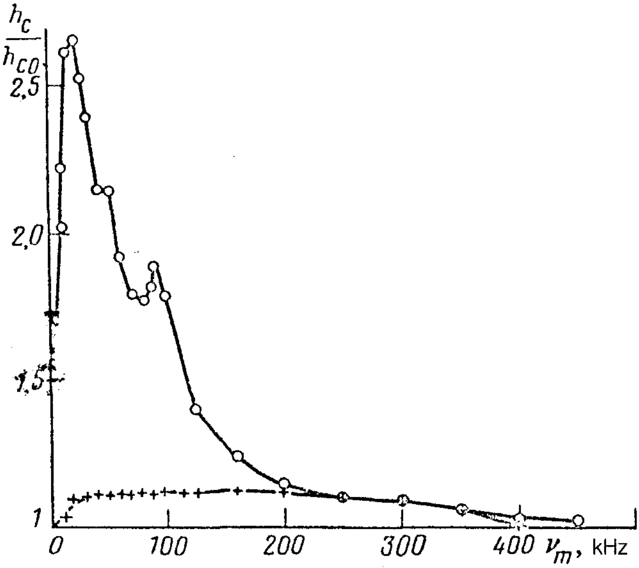

FIG. 1. Effect of a modulation on the pump thresholds in the very hard region ($h_{c10}/h_{c20} = 5.65$, $\nu_p = 778.7$ MHz, $T = 1.76$ K, $H = 1.08$ kOe, $H_m = 1.96$ Oe). ○—h_{c2}; + $-h_{c1}$.

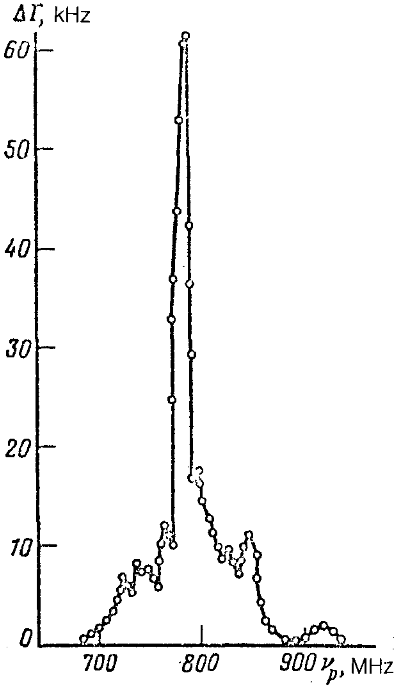

FIG. 2. Frequency dependence of the part of the relaxation in $CsMnF_3$ which turns off ($T = 1.86$ K, $H = 0.8$ kOe).

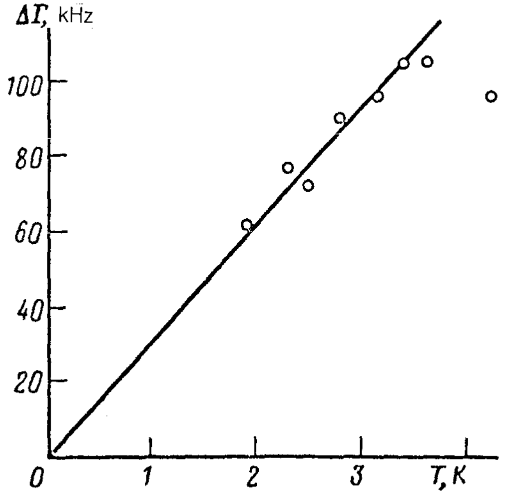

FIG. 3. Temperature dependence of the part of the relaxation which turns off, ΔΓ ($H = 670$ Oe, $\nu_p = 780$ MHz).

channel off by means of an auxiliary microwave relaxation with a frequency $\nu_a = \nu_d$. We accordingly carried out an experiment in which we exposed the sample to a probe beam $h_a \cos \omega_a t$, with $\vec{h}_a \perp \vec{H}$, in addition to the main pump. Under the condition $\nu_a = \nu_p/2$, this second pump has a substantial effect on the threshold h_{c1}. This effect is seen first at amplitudes $h_a \sim 3 \times 10^{-4}\, h_{c1}$. With increasing power of the probe pump,

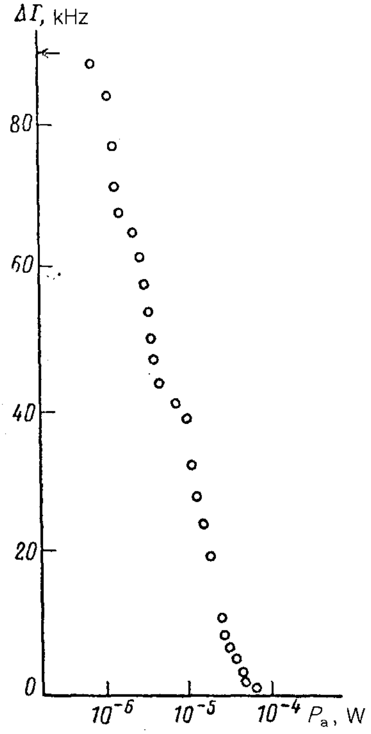

FIG. 4. The part of the relaxation which turns off versus the power of the probe pump, with a frequency $\nu_a = \nu_p/2 = 391.00$ MHz ($T = 4.2$ K, $H = 750$ Oe). The arrow shows the value of ΔΓ at $P_a = 0$.

P_a, the threshold h_{c1} decreases, tending toward h_{c2}. In other words, the component $\Delta\Gamma$ drops to zero (Fig. 4). No effect of the probe radiation on the threshold h_{c2} is observed. As the frequency ν_a is shifted away from $\nu_p/2$, the effect on the threshold h_{c1} rapidly decreases. The width of this line characterizes the true defect relaxation rate: $\Delta\nu_d$ (4.2 K) $\approx$ 20 kHz, $\Delta\nu_d$ (1.5 K) $\approx$ 10 kHz. These figures are two orders of magnitude smaller than the width of the peaks in Fig. 2. That width apparently reflects a frequency distribution of the defects.

We conclude with a look at the nature of these defects. It was suggested in Ref. 5 that the nuclear spin waves are hard because of a deviation from stoichiometry in the crystal, specifically, an excess of Mn atoms. In the present study we measured the hardness for several samples with a deviation from stoichiometry. We found that an excess of any of the elements Mn, Cs, F had no important effect on either the frequency or the size of the $\Delta\Gamma$ peak in the relaxation of nuclear spin waves. By grinding a sample we were able to increase the part of the relaxation which turns off by a factor of about 2, probably because of an increase in the number of dislocations in the crystal. Our results thus support the conclusions reached in Refs. 2, 6, and 7, where dislocations were singled out as the defects which had the greatest effect on magnon relaxation in $CsMnF_3$.

[1] A. V. Andrienko, V. I. Ozhogin, V. L. Safonov, and A. Yu. Yakubovskiĭ, Zh. Eksp. Teor. Fiz. **84**, 1158 (1983) [Sov. Phys. JETP **57**, 673 (1983)].

[2] A. V. Andrienko, V. I. Ozhogin, V. L. Safonov, and A. Yu. Yakubovskiĭ, Usp. Fiz. Nauk **161**(10), 1 (1991) [Sov. Phys. Usp. **33**, 793 (1991)].

[3] V. V. Zautkin, V. S. L'vov, B. I. Orel, and S. S. Starobinets, Zh. Eksp. Teor. Fiz. **72**, 272 (1977) [Sov. Phys. JETP **45**, 143 (1977)].

[4] A. V. Andrienko, V. I. Ozhogin, V. L. Safonov, and A. Yu. Yakubovskiĭ, Zh. Eksp. Teor. Fiz. **89**, 2164 (1985) [Sov. Phys. JETP **62**, 1249 (1985)].

[5] A. V. Andrienko, V. I. Ozhogin, V. L. Safonov, and A. Yu. Yakubovskiĭ, Zh. Eksp. Teor. Fiz. **87**, 1509 (1984) [Sov. Phys. JETP **60**, 868 (1984)].

[6] Yu. M. Bun'kov, V. V. Dmitriev, and V. L. Safonov, Fiz. Tverd. Tela (Leningrad) **27**, 1027 (1985) [Sov. Phys. Solid State **27**, 623 (1985)].

[7] A. V. Andrienko, Zh. Eksp. Teor. Fiz. **100**, 1358 (1991) [Sov. Phys. JETP **73**, 752 (1991)].

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