Nuclear spin waves in antiferromagnetic $RbMnF_3$

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Parametric excitation of pairs of nuclear spin waves is investigated in cubic antiferromagnetic $RbMnF_3$. On the assumption that the generally accepted mechanism of parametric excitation is operative, an investigation is made of the variations of parallel-pumping threshold field with frequency, external magnetic field, and temperature that occur as a result of a change of the rate of relaxation of nuclear spin waves upon change of these parameters. It is shown that the principal mechanism of relaxation is due to the existence in the specimen of a nuclear magnetic resonance branch independent of the magnetic field of the specimen and can be described as $\eta\sim[(\omega_p/2-\omega_2^2]^{-2}$, where ω_p is the pumping frequency, ω_2 is the frequency of the field-independent NMR branch, and η is the rate of relaxation of the nuclear spin waves. An additional contribution to the relaxation is observed, which is switched off in the state in which the excited magnons lie below the field-independent branch of the nuclear spin waves. This contribution is interpreted as a process of decay of a spin wave into a spin wave of the second branch and a phonon. The presence of such a process makes possible an estimation of the bandwidth of the field-independent spin-wave branch at constant frequency.

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INTRODUCTION

$RbMnF_3$ is a cubic antiferromagnet with a small value of the crystalline anisotropy. Parametric excitation of nuclear spin waves by an electromagnetic field in this material has been investigated both experimentally[1,2] and theoretically.[3,4] In contrast to $MnCO_3$[5] and $CsMnF_3$,[1] where the experimental data agree well with theory, $RbMnF_3$ is far from a satisfactory description. Although there are a few papers on investigation of parametric excitation,[1,2,4] the data practically fall into a single characteristic range for relaxation of nuclear spin waves. This fortuitous situation has led to a complete lack of clarity in the picture of nuclear spin-wave relaxation in $RbMnF_3$. We have investigated parametric excitation of nuclear spin waves over a relatively broad range of variation of the temperature (from 4.2 to 1.24 K) and of the pumping frequency (from 970 to 1237 MHz). It is shown in the paper that a characteristic of nuclear spin-wave relaxation in $RbMnF_3$ is the presence of a second branch of nuclear magnetic resonance. Here the experimental situation is quite clear, although for understanding of the relaxation mechanism it seems that theoretical calculations are necessary.

Nuclear magnetic resonance in $RbMnF_3$ has been studied before.[6,7] There it was shown that the observed relations are described with good accuracy by the formulas given by de Gennes *et al.*[8] for strongly coupled electronic and nuclear magnetic systems,

$$\omega_{1,2}^2=\omega_0^2\left(1-\frac{2\gamma_e^2H_EH_N}{\Omega^2_{0\,1,2}}\right), \tag{1}$$

where $\omega_{1,2}$ are the nuclear resonance frequencies of the two branches 1 and 2, related to the corresponding AFMR modes; ω_0 is the nuclear resonance frequency in the hyperfine field of the electrons in the absence of dynamic coupling ($\omega_0/2\pi=\gamma_n AM=686$ MHz; γ_n is the gyromagnetic ratio for nuclei, A is the hyperfine interaction constant, and M is the magnetization of the electronic sublattices); $H_E=830$ kOe is the effective exchange field of $RbMnF^3$; H_N is the hyperfine field of the nuclei acting on the electrons ($H_N=A\langle m\rangle=9.43/T$ [Oe]; $\langle m\rangle$ is the mean magnetization of the nuclei, T is the absolute temperature); $\Omega_{0,1,2}$ are the branches of the AFMR spectrum. For $RbMnF_3$ above the sublattice flip field $H_{sf}\approx 2.3$ kOe, the antiferromagnetic resonance has two branches. When the direction of the external magnetic field H is parallel to the [001] axis, there are a field-dependent branch

$$\Omega_{10}^2=\gamma_e^2(H^2-{}^3/_2H_AH_E+2H_EH_N) \tag{2}$$

and a field-independent branch

$$\Omega_{20}^2=\gamma_e^2(3H_AH_E+2H_EH_N),\quad {}^3/_2H_AH_E=H_{sf}^2. \tag{3}$$

It was shown earlier[9] that in the neighborhood of the intersection of the branches ω_1 and ω_2 of the NMR spectrum (the corresponding value of the field is $H_c\approx 4$ kOe), there is a strong interaction of the modes, which leads to a distortion of the relations (1). This interaction is not described solely by a single geometrical factor of inclination of the magnetic field to the direction [001].

METHOD

Parallel pumping is a convenient method of study of nuclear spin waves in magnetically ordered substances. This phenomenon consists in the following: a photon with frequency ω_p and practically zero momentum decays into two magnons with frequencies $\omega_p/2$ and wave vectors k and $-k$. The frequency of the nuclear spin waves is determined by the formula[8]

$$\omega_{1k}^2=\omega_0^2\left(1-\frac{2\gamma_eH_EH_N}{\Omega_{1k}^2}\right), \tag{4}$$

where $\Omega_{1k}^2=\Omega_{10}^2+v^2k^2$; v is the velocity of electronic spin waves.

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Since under the conditions of the experiment $\omega_{1k} = \omega_p/2$ is a constant quantity, $\Omega_{1k} = \text{const}$; and on equating the values of Ω_{1k} with $k=0$, and with $k \neq 0$, we get an expression that determines the value of the wave vector:

$$H_0^2 - H^2 = v^2 k^2, \tag{5}$$

or

$$k = \frac{1}{v}(H_0^2 - H^2)^{1/2} = \frac{1}{v}\mathcal{H}, \tag{6}$$

where H_0 is the magnetic field corresponding to uniform precession of the nuclear spins at half the pumping frequency.

Thus in a magnetic field less than the NMR field, excitation of spin waves is possible. Investigation of parallel pumping gives a possibility of obtaining information on the rate of relaxation of nuclear spin waves. In parametric excitation of any oscillatory system, characteristic oscillations will be excited in the system when the energy communicated to this system from outside exceeds the internal dissipation of energy. The energy losses of the system of spin waves are determined by their rate of relaxation η. The energy that is pumped into the magnetic system is determined by the coupling mechanism and the value of the alternating magnetic field. The formula relating the value of the critical field h_c to the rate of relaxation of nuclear spin waves $\eta_n(k)$ has the form[4]

$$\gamma h_c = \frac{2\eta_{nk}\Omega_{1k}^4\omega_{1k}}{\gamma H \omega_0^2 2\gamma^2 H_E H_N}. \tag{7}$$

Consequently, by measuring the value of the critical field necessary for excitation of spin waves with wave vector **k** it is possible to obtain the value of the rate of relaxation $\eta_n(k)$.

EXPERIMENT

The experimental apparatus, a block diagram of which is shown in Fig. 1, is an ordinary transmission spectrometer. The experiment measured the variation of the power passing through the resonator as a function of the value of the constant magnetic field.

Microwave power from the signal generator 1, through the attenuators 2 and 4 and the resonator 3 containing the specimen, enters the input of the measuring receiver 5. The signal further enters the compensator 6, in which there is subtracted from it a voltage from the reference source 8 such that the output signal is proportional to the change of absorption in the specimen. The signal, amplified in the compensator, is recorded on the XY-recorder 7, to whose X coordinate is fed the voltage from the Hall detector 12.

In work by the pulse method, the microwave generator is modulated by pulses from the pulse generator 9; to the output of the compensator is connected the stroboscopic voltmeter 10, which measures the voltage at the end of the pulse after the addition that corresponds to excitation of nuclear spin waves in the specimen.

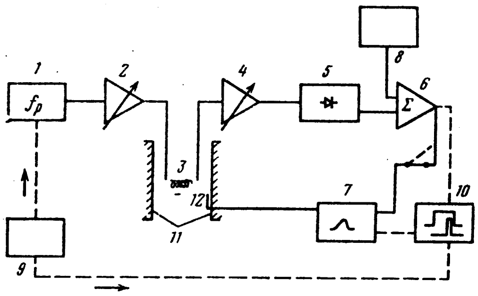

FIG. 1. Block diagram of measurement apparatus for observation of parametric excitation of nuclear spin waves. 1, pumping-field generator; 2 and 4, variable attenuators; 3, spiral resonator containing the specimen; 5, receiver; 6, level compensator; 7, recorder; 8, constant-voltage source; 9, pulse generator; 10, stroboscopic voltmeter; 11, electromagnet poles; 12, Hall detector.

To prevent overheating of the specimen, which was placed in gaseous helium, the microwave generator was modulated by pulses of large spacing ($\sim 3 \cdot 10^3$); the mean power entering the resonator did not exceed 30 μW. The $RbMnF_3$ specimen, in the form of a parallelopiped with dimensions $2 \times 2.5 \times 4$ mm with edges parallel to the [100] axes, was placed in a spiral resonator made from copper wire of diameter 0.5 mm. The resonator had length ~7 to 10 mm and internal diameter 4 mm. The Q of such a resonator at liquid-helium temperature has a value of the order (1 to 1.5) $\cdot 10^3$.

The field in the resonator was estimated with the formula

$$h^2 = \frac{4\pi QP}{f_p V}, \tag{8}$$

where h is the amplitude of the alternating field, Q is the quality factor, P is the power entering the resonator, f_p is the characteristic frequency of the resonator, and V is the volume bounded by the spiral. This formula is derived on the assumption that half the field energy is concentrated in the volume bounded by the spiral and that the high-frequency field within the spiral is uniform.

At the critical coupling and power 1 W, we get a value of the field of order 40 Oe ($f_p = 10^9$, $Q = 10^3$). It is to be expected that in first approximation, the value of the microwave magnetic field will be independent of frequency, since the frequency changes with change of the length of the spiral and, for constant diameter and pitch of the winding, it turns out that $V \sim l$ whereas $f_p \sim l^{-1}$, where l is the length of the spiral.

To estimate the error of determination of the magnetic field by formula (8), a measurement was made of the alternating magnetic field in the resonator by saturation of the EPR line of an iminoxyl radical at frequency 950 MHz at room temperature. The error in determination of the field by formula (8) does not exceed 15%. Allowing for the error in establishment of the critical coupling and in determination of the Q, the generator power, and the attenuator calibration, we estimate the total error of determination of the amplitude of the magnetic field at ± 30%. An exception is the measurement at frequency 1237 MHz, which lies beyond the quaranteed limits of our generator.

The measurement results obtained by the pulse and continuous methods show practically no difference. The experiments were done at various stages of evacuation of liquid helium in a magnetic field up to 7.5 kOe, obtained in a laboratory electromagnet.

EXPERIMENTAL RESULTS

Figure 2 gives experimental curves of the parallel susceptibility of $RbMnF_3$ specimen at frequency 1159 MHz, at temperature 1.24 K and with $\mathbf{h} \| \mathbf{H} \|$ [001]. When the alternating magnetic field reaches a critical value, an additional absorption (1) occurs on the curve of the imaginary part of the susceptibility; it corresponds to excitation of a pair of spin waves near the uniform precession at half the pumping frequency. On increase of the value of the alternating magnetic field, the region of extra absorption spreads to smaller magnetic fields; this corresponds to excitation of spin waves with larger wave vectors. At a magnetic field of about 4 kOe there is a deep minimum of the above-threshold susceptibility. This field, as was shown earlier,[9] corresponds to the intersection of the branches of nuclear magnetic resonance in $RbMnF_3$. The existence of this minimum attests to the strong effect, in parametric excitation, of interaction of the two branches of nuclear spin waves in $RbMnF_3$. The magnetic field limiting the curve of extra absorption (Fig. 2) corresponds to the fact that at this field nuclear spin waves begin to be excited; or, equivalently, at this field the alternating magnetic field h has a critical value.

Thus from the experimental curves (Fig. 2) one can plot the dependence of the value of the critical field h_c on the external magnetic field H. Figure 3 shows the variation of the amplitude of the threshold high-frequency field with the external magnetic field for several temperatures and for pumping frequency 1237 MHz. It is evident that the critical field h_c is determined by the value of the constant magnetic field and is independent of temperature.

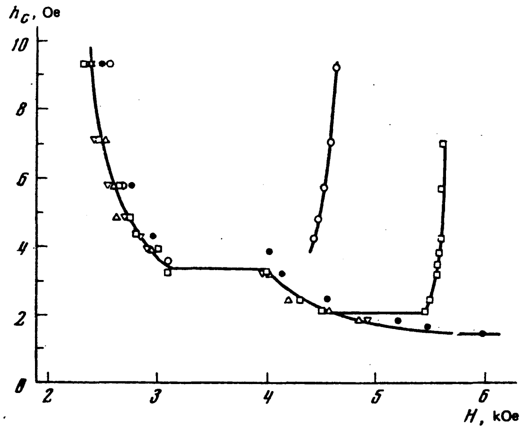

FIG. 3. The function $h_c(H)$ for pumping frequency 1237 MHz, for various temperatures: •, 1.24 K; ▽, 2.09 K; △, 2.18 K; □, 2.51 K; ○, 4.14 K.

Figure 4 shows the functions $h_c(H)$ for several frequencies at temperature 1.24 K. As with the temperature dependence (Fig. 3), it is evident that, within the error of measurement of h_c, the data for $H>4$ kOe are independent of the pumping frequency and are determined by the external magnetic field. Here, though, it is evident that the function $h_c(H)$ for different frequencies can no longer be described by a single law. The relative accuracy of the h_c measurements for each frequency individually is considerably higher than for the absolute estimate of h_c, and Fig. 4 shows that the functions $h_c(H)$ for f_p = const intersect and can hardly be reduced to some family of curves of a function of H alone.

A characteristic feature of the data presented in Figs. 3 and 4 is the presence of a plateau on the $h_c(H)$ curve in the magnetic-field range below 4 kOe. Observation of absorption curves, similar to those given in Fig. 2, in the plateau region at large gain shows that what occurs there is in fact a plateau and not a minimum of h_c. Since near field 4 kOe there is an abrupt decrease of the nonlinear high-frequency susceptibility χ'', here there will be a large error in the determination of the value of the magnetic field that bounds the absorption curve. The magnetic-field range below 3 kOe is also

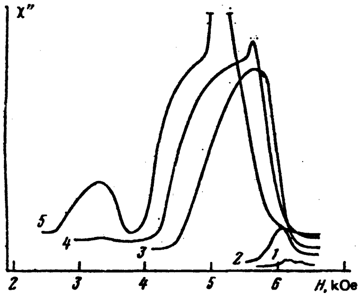

FIG. 2. Above-threshold absorption in a specimen under parallel pumping. Curve 1 corresponds to the onset of above-threshold absorption. The other curves correspond to increase of the pumping power: $P_5>P_4>P_3>P_2>P_1$. On curves 4 and 5 is seen the beginning of a second process under parallel pumping. [10] Pumping frequency f_p=1159 MHz, T=1.24 K.

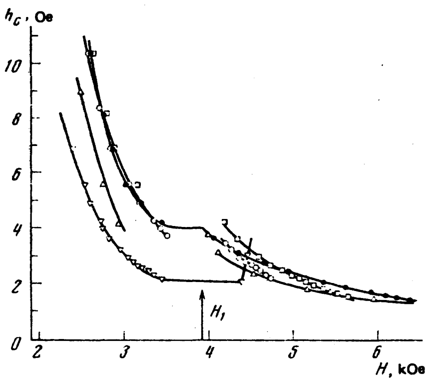

FIG. 4. Dependence of the critical amplitude of the alternating field on the value of the constant magnetic field, $h_c(H)$, for various pumping frequencies: ▽, 970 MHz; ○, 1046 MHz; □, 1150 MHz; •, 1206 MHz; △, 1237 MHz; T=1.24 K.

poorly suited for accurate description of parallel pumping, since here the NMR spectrum becomes more complicated[9] because of the proximity of the flip field.

To clarify the relaxation mechanism of nuclear spin waves, investigations were made of the variation of the NMR line width in $RbMnF_3$ with magnetic field and temperature (Fig. 5). It was found that the line-width ΔH is independent of temperature and inversely proportional to the magnetic field for fields above 4 kOe; at a field ~4 kOe, there is a singularity of the NMR line-width, which suggests interaction of the NMR modes in $RbMnF_3$.

Here it should be mentioned that the NMR line-width in a sense is independent of frequency. If we choose some constant magnetic field, then at different temperatures the NMR line will be observed in this field at different frequencies, as follows from equations (1) and (2). Here the NMR line-width will not change but will depend only on the field.

DISCUSSION OF RESULTS

As has already been pointed out, observation of parametric excitation gives information about the rate of relaxation of the corresponding quasiparticles. Starting from Ref. 5, we suppose that in the case under investigation, the operative mechanism of excitation of nuclear spin waves is that described by Hinderks and Richards[4] and Ozhogin and Yakubovskiĭ.[11] It gives a relation between the value of h_c and the rate of relaxation in the form

$$h_c=2\eta_{nk}\frac{2H_EH_N\omega_0^2\omega_{1k}}{(\omega_0^2-\omega_{1k}^2)^2H}. \qquad (9)$$

For $RbMnF_3$ this relation can be written in the form

$$\eta_n=\frac{h_cHT}{2\cdot 16.03\cdot f(\omega_p)}, \qquad (10)$$

where η_n is the rate of relaxation of nuclear spin waves, measured in the same units as is ω_p, and where H is the external magnetic field and h_c is the critical threshold field, expressed in kOe. As is evident from this relation, the fact that h_c is independent of temperature and pumping frequency leads to a dependence of η_n on these quantities. By use of formula (10) we have plotted the dependence of η_n on $\mathscr{H}=(H_0^2-H^2)^{1/2}$ (Fig. 6), where H_0 is the value of the magnetic field at which nuclear magnetic resonance is observed at frequency $\omega_p/2$ at the given temperature, and where H is the current value of the magnetic field according to the $h_c(H)$ relation (Figs. 3 and 4). The quantity $\mathscr{H}=vk$, where k is the wave vector of the spin waves that are being excited, and where v is the velocity of electronic antiferromagnetic spin waves for $RbMnF_3$. In Fig. 6 we show values of η for fields above 4 kOe, where one can expect a simple $\eta(k)$ relation. As is seen from the figure, the rate of relaxation with some accuracy has the form of a linear function of k. For a single frequency, it increases with increase of temperature, while variations at a single temperature give an increase of the relaxation rate with lowering of the frequency.

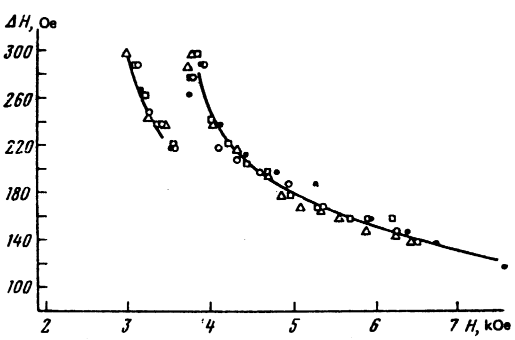

FIG. 5. NMR line-width in $RbMnF_3$, as a function of external magnetic field at various temperatures: △, 1.25 K; □, 2.29 K; ●, 4.2 K.

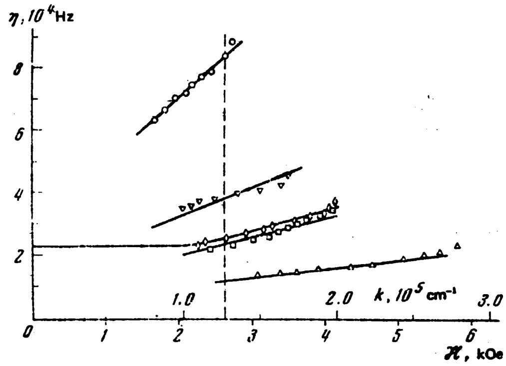

FIG. 6. Variation of the relaxation rate of nuclear spin waves (1[sec^{-1}] = 2π[Hz]) with wave vector $k \sim \mathscr{H} = (H_0^2 - H^2)^{1/2}$: ○, 1046 MHz, T=1.24 K; ▽, 1206 MHz, T=2.15 K; ◇, 1206 MHz, T=1.79 K; □, 1159 MHz, T=1.24 K; △, 1206 MHz, T=1.24 K. For small values of k, the relaxation rate is equal to the minimum ordinate of the given series. This is shown for the series ◇. Results are given for magnetic-field values H > 4 kOe.

As has already been mentioned in the discussion of the above-threshold susceptibility, the presence of a second NMR branch has a pronounced effect on parametric excitation. We assumed that in the relaxation of the branch of nuclear spin waves being excited there is also a contribution determined by the coupling with the second branch, and we plotted graphs of the data at our disposal on the rate of relaxation for various frequencies and temperatures, as functions of the detuning between half the pumping frequency and the frequency

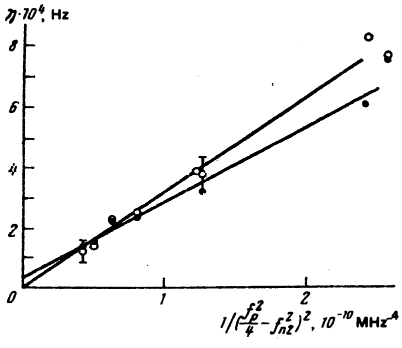

FIG. 7. Variation of the relaxation rate of nuclear spin waves in $RbMnF_3$ with the squared detuning of half the pumping frequency with respect to the frequency of the field-independent branch of the NMR: ○, $\mathscr{H}$=2.6 kOe; ●, $\mathscr{H}$=0.

of the magnetic-field-independent NMR branch (ω_2). Since ω_2 depends on temperature, the calculated value $\omega_2(T)$ was used for each temperature. The variations of the rates of relation for $\mathcal{H}=2.6$ kOe (the dotted straight line in Fig. 6) and for $\mathcal{H}=0$ with the value of $[(\omega_p/2)^2-\omega_2^2]^{-2}$ are shown in Fig. 7. In this way, as is evident from the figure, one can describe the principal contribution to the relaxation of nuclear spin waves in $RbMnF_3$. Other relaxation mechanisms under these conditions can be studied at large pumping frequencies (so that the detuning may be appreciable). In our case the maximum detuning was $\omega_p/2-\omega_2\sim150$ MHz; there the relaxation rate has a value of $\sim10^4$ Hz $=2\pi\cdot10^4$ sec^{-1}, which is already close to the value obtained in the theory of Richards,[3] $\eta_n=0.15\,kT$ ($\eta=3.72\cdot10^4$ sec^{-1} for $k=2\cdot10^5$ cm^{-1}, $T=1.24$ K). At a pumping frequency below ω_2, the region of beyond-threshold absorption falls within the magnetic-field range from 4 kOe to the sublattice flip field $H_{sf}\sim2.4$ kOe. In this range the experimental data are poorly suited for analysis, since from 4 to ~3.2 kOe there is a plateau on the $h_c(H)$ curves, while below, from 3 to 2.3 kOe, there begins a rapid increase of $h_c(H)$, due apparently to nonuniformity of the specimen with respect to spin flop. All previous work on parametric excitation of spin waves[1,2,4] has been done in precisely this, in our view unfortunate, range of magnetic fields.

We turn now to the plateau region, which also indicates some characteristic mechanism of relaxation of the nuclear spin waves that are being excited in RbMnF (or, more generally, in a system wih two spin-wave branches that lie close to each other). A plateau on the $h_c(H)$ curve indicates, if one turns to the expression (10) for the rate of relaxation, a decrease of relaxation rate on decrease of magnetic field. In other words, on decrease of the magnetic field from 4 to 3.2 kOe there occurs a switching off of some relaxation mechanism. In Fig. 8, the decrease $\Delta\eta$ of the relaxation rate is separated out graphically in the function $\eta(\mathcal{H})$. On passage through the plateau region, there occurs a single significant change in the energy spectrum of the nuclear spin waves. At fields larger than 4 kOe, the spectrum of the spin waves being excited lies above the field-independent spectrum of nuclear spin waves, while at fields smaller than 3.2 kOe it lies below it. This is indicated schematically in Fig. 9. In the paper of Ozhogin and Yakubovskiĭ[11] it is pointed out that spin waves of different symmetries, as is true of ω_{1k} and ω_{2k}, are coupled only via elastic interaction. Thus the relaxation mechanism corresponding to the start of the plateau may be described as follows: at fields larger than 4 kOe, the spin waves being excited can decay into a spin wave of the field-independent branch and a phonon, in accordance with the laws of conservation of energy and of momentum. But at small fields, such a process is prohibited energetically. The process of fusion of the excited spin waves with a phonon, with transition to the field-independent branch, is limited by the small number of thermal phonons at such low frequencies. The plateau itself is formed in consequence of the variation of the number of states of the field-independent band of the spin-wave spectrum, into

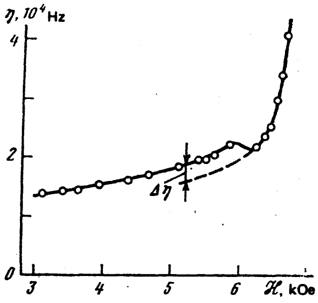

FIG. 8. Plot on the basis of the experimental $\eta(k)$ relation ($f_p=1206$ MHz, $T=1.24$ K), illustrating the existence of an additional relaxation rate $\Delta\eta$ when $H>4$ kOe. The section of the $\eta(k)$ curve with negative slope corresponds to the plateau region.

which a transition is possible with emission of a phonon, to the degree that this band intersects the parametrically excited spin waves. These considerations are illustrated in Fig. 9. The horizontal line with ordinate $\omega_p/2$ corresponds to the shift of the state of the spin waves excited parametrically in parallel pumping with decrease of the magnetic field. For $H>H_c$, the decay process pictured in the insert of this figure is possible; for $H<H_c$, the process is forbidden. The section between the vertical arrows shows the k range corresponding to the plateau on the $h_c(H)$ curve.

By starting with these considerations, one can estimate the width of the spin-wave spectrum ω_{2k}. The estimate gives $0.8\cdot10^4$ and $1.5\cdot10^4$ cm^{-1}, respectively, for pumping frequencies 1206 and 1046 MHz at temperature 1.24 K. The values of the change of relaxation rate are $\Delta\eta\sim0.3\cdot10^4$ Hz ($f_p=1206$ MHz) and $\sim0.9\cdot10^4$ Hz ($f_p=1046$ MHz).

CONCLUSION

The results of the experiments show that a determining influence is exerted on the relaxation rate of nuclear spin waves by the magnetic-field-independent branch of nuclear spin waves that exists in $RbMnF_3$. In the first place, this is some pair mechanism of relaxation (a second-order Suhl process), corresponding to excitation by a pair of magnons from the first branch of two magnons from the second branch with $k=0$. This

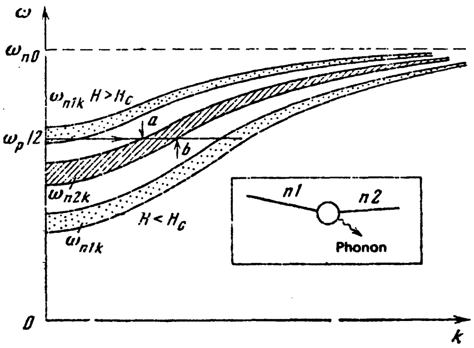

FIG. 9. Sketch of the energy spectrum of nuclear spin waves in $RbMnF_3$ for $H>H_c$ and for $H<H_c$; H_c is the magnetic field at which the two branches of the nuclear spin-wave spectrum coincide. The horizontal straight line with ordinate $\omega_p/2$ corresponds to the change of the state of the parametrically excited spin waves with decrease of the magnetic field from H_0 to H_{sf}. The vertical arrows bound the region corresponding to the plateau on the $h_c(H)$ curve. The insert shows a sketch of the process of decay of a magnon of the field-dependent branch of the spectrum into a magnon of the second branch and a phonon.

follows from the determining influence of the value of ω_{20} on the relaxation rate. The law of conservation of momentum requires that the process be a pair process. The reason for selection of spin waves with $k=0$ remains unclear. The selection of this mechanism removes the experimental contradictions with respect to the large difference in relaxation rate between $RbMnF_3$ and $MnCO_3$, in which the second branch is close to ω_0 and exerts no significant influence on the relaxation. The pair nature of the process may explain the usually present disagreement between the critical amplitudes for parametric excitation of different spin waves in a magnetic material. The critical fields are connected by the relation[11]

$$h_c^{en}=(h_c^{ee}h_c^{nn})^{1/2},$$

where h_c^{en} is the threshold for excitation of an electronic and nuclear spin-wave pair, h_c^{ee} is the threshold for excitation of two electronic magnons, and h_c^{nn} is the threshold for excitation of two nuclear magnons. In the expression for h_c^{en}, in the role of relaxation rate there stands a quantity that corresponds to attenuation of an individual particle, whereas in h_c^{ee} and h_c^{nn} the attenuation may be supplemented by a pair mechanism of relaxation. In $RbMnF_3$ we have investigated parametric excitation of a mixed process—one electronic and one nuclear spin wave. Cole and Courtney[14] obtained the rate of relaxation of electronic spin waves from data on saturation of antiferromagnetic resonance. Comparison of these data gives a rate of relaxation of nuclear spin waves that is two orders of magnitude smaller than that obtained from experiments on parametric excitation of a pair of nuclear spin waves. Thence also follows a completely observable value of the threshold for the process of generation of two electronic spin waves, yet such a process has not yet been observed. This indicates the possible presence of an influence of the second AFMR branch on the process of excitation of a pair of electronic spin waves, that is the existence of a mechanism similar to that considered in the present work in the antiferromagnetic system of a $RbMnF_3$ specimen.

The additional relaxation rate, also determined by the presence of a second branch in the nuclear spin-wave spectrum, corresponds to decay of a parametrically excited magnon into a nuclear magnon of the field-independent branch and a phonon. This relaxation rate gives a value comparable with the theoretical estimate given by Richards[3] for scattering of nuclear spin waves within the framework of the Suhl-Nakamura[12,13] interaction; that is, it is also a strong mechanism of relaxation. The presence of this additional relaxation rate provides a possibility of investigating the spin-wave band of the second branch, in consequence of the shutting off of the interaction on passage of the parametrically excited spin waves through the band of the nuclear spin waves of the field-independent branch.

As regards concrete separation of all the relaxation mechanisms, including separation out of the Richards[3] mechanism that was treated theoretically, we consider that premature without appropriate theoretical calculations. The errors of measurement are quite large, and therefore it is difficult to determine the functional relations between the relaxation rate and the parameters of the experiment.

In conclusion, the authors take this opportunity to express their thanks to V. I. Ozhogin and A. Yu. Yakubovskiĭ for kindly providing the single crystal of $RbMnF_3$ on which these measurements were made.

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