Subharmonic radiation during parametric excitation in the nuclear-spin-wave region

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Radiation at a frequency equal to one-half the pump frequency has been observed in the antiferromagnetic material $MnCO_3$ when the latter is excited by the method of parallel pumping of nuclear-spin waves and the phonons associated with them.

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Parametric excitation of spin waves by the parallel-pumping method corresponds to the decay process of a microwave-field photon into two spin waves. The energy and momentum conservation laws must be satisfied:

$$\omega_p = \omega_{1k} + \omega_{2k} ,$$

$$\mathbf{p} = \mathbf{k}_1 + \mathbf{k}_2 .$$

If we excite the spin waves of one branch (degenerate process) and ignore the wave vector of the photon, then the equations can be simplified to

$$\omega_p = 2\omega_k ,$$

$$\bar{\mathbf{k}}_1 = -\bar{\mathbf{k}}_2 = \bar{\mathbf{k}} .$$

In this case the magnetization oscillations at a frequency $\omega_p/2$ exist in the sample. Since the wave vectors $|\mathbf{k}| \gg 1/l$, where l is the characteristic size of the sample, are usually excited, it is hard to expect an appreciable emission of the electromagnetic field by the sample at a frequency $\omega_p/2$. It can be expected either in the case of uniform precession or in the presence of a mechanism for conversion of the excited spin waves into uniform precession ($|\mathbf{k}| = 0$). The development of parametric excitation in $MnCO_3$ was investigated by the authors of Ref. 1.

The parametric excitation was accomplished by using the method described in Refs. 1 and 2. The sample was placed in a spiral cavity (for measurements at a frequency of 1175 MHz). The spiral cavity was made from 0.4-mm-diam copper wire; the diameter of the spiral was 5 mm. A styrofoam holder was used to insert the spiral into a 10-mm-diam copper tube. Coaxial leads supplied power to the tube. Coupling with the spiral cavity was made via pins, which were connected to the ends of the sprial. A loop was mounted in series with the spiral to receive the radiation (the plane of the loop is vertical and parallel to the spiral axis; the spiral axis is horizontal). The loop was used as an inductance in the tunable circuit (500 to 700-MHz frequency). The signal was removed from the loop and entered a receiver with the necessary band-width. Direct influence of the pump circuit on the receiver was not evident in the control experiments.

$MnCO_3$ is an antiferromagnetic material with anisotropy of the easy-plane type with a weak ferromagnetism.[3] Parallel pumping was achieved and magnetization oscillations at the subharmonic frequency in the easy plane (the plane of maximum susceptibility of the antiferromagnetic system) were received when the easy plane of the sample was oriented horizontally and the static magnetic field was parallel to the spiral axis.

Figure 1 shows typical absorption curves in the cavity with the sample for parallel pumping. The curve *a* corresponds to excitation of nuclear-spin waves within the band in which absorption exists (the interval from 1 to 2). The curve *b* corresponds to excitation of magnetoelastic waves in the interval from 3 to 4 in addition to the excitation of nuclear-spin waves in the interval from 1 to 2. The curve *c* corresponds to a well-developed process of magnetoelastic-wave excitation in the (3, 4) interval, while a thermal instability of the nuclear-magnetic system[4] has already occurred in the (3, 5) interval.

Figure 2 illustrates the receiver-detected radiation at the frequency $f_p/2$ for parametric-excitation conditions analogous to those in Fig. 1. During the excitation of nuclear-spin waves the radiation is observed only near $k=0$, i.e., in a magnetic field corresponding to nuclear-magnetic resonance at the frequency $f_p/2$. Excitation of sufficiently large $k(\gtrsim 5\times 10^4\ \mathrm{cm}^{-1})$ is not accompanied by a noticeable subharmonic radiation. Excitation of magnetoelastic waves (curve *b*) corresponds to radiation in the entire excitation interval. In this case it is nonuniform (deeply modulated, low-frequency noise with a characteristic frequency of the order of 10–100 Hz). At such imperfect reception (low filling coefficient) the radiated power can reach a value of 10^{-8} W.

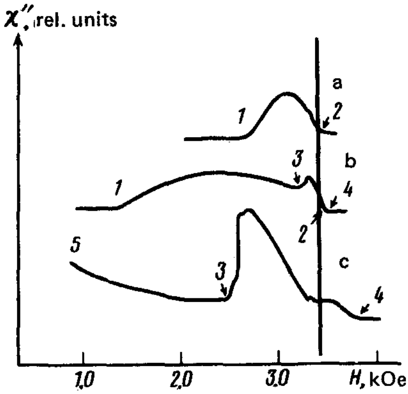

FIG. 1. Some characteristic $\chi''(H)$ dependences, which are observed during parallel pumping. Curve *a*, nuclear-spin waves are excited in the (1, 2) interval. Curve *b*, some nuclear-spin waves are excited in the (1, 3) interval in addition to excitation of magnetoelastic waves in the (3, 4) interval. Curve *c*, superheated nuclear-spin waves in the (5, 3) interval and a developed magnetoelastic-wave-excitation process in the (3, 4) interval.

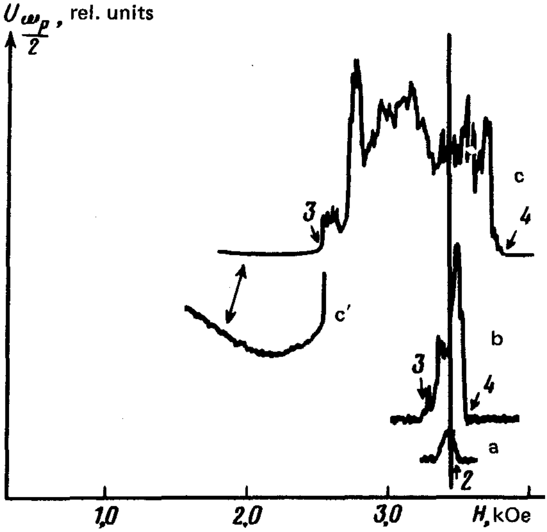

FIG. 2. Amplitude of the subharmonic radiation (frequency $f = 587.5$ MHz) corresponding to Fig. 1. The notations for the curves and the intervals are the same as in Fig. 1. Curves *a*, *b*, and *c* correspond to 0-*db* input attenuation of the receiver and curve *c*′ corresponds to 20-db attenuation.

At a higher power (curve *c*) a much weaker radiation is also observed in a superheated nuclear system in which parallel pumping is used.

Thus, a parametric excitation of quasiparticles in the region of nuclear-spin waves can produce subharmonic radiation. This radiation occurs when the wave vectors of the excited quasiparticles are $k \lesssim 5 \times 10^4$ cm^{-1}. For pure spin waves it occurs in the absorption band for NMR at a frequency of $f_p/2$. The wave vector of the magnetoelastic waves is of the same order of magnitude $2\pi f_p/s \approx 10^4$ cm^{-1}, where s is the velocity of sound. The wave vector also reduces to these values as a result of superheating instability.[4] A comparison of the characteristic wave vector of the intracrystalline inhomogeneities with the NMR line width shows that the estimated values are of the same order of magnitude $k \approx 10^4$ cm^{-1}. As shown in Eastman's paper,[5] this inhomogeneity for RbMnF$_3$ is determined by nonuniform strains in the crystal, which are associated with its defective structure. We can assume that quasiparticles with wave vectors in this range can be converted to homogeneous magnetization oscillations by inhomogeneities in the magnetic structure of the sample, which arise because of the defective structure of the crystal.

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