Acoustic nuclear spin echo in the antiferromagnets $KMnF_3$ and $RbMnF_3$

Kh. G. Bogdanova, V. A. Golenishchev-Kutuzov, and A. A. Monakhov

Kazan' Physicotechnical Institute, USSR Academy of Sciences
(Submitted February 5, 1977)
Pis'ma Zh. Eksp. Teor. Fiz. **25**, No. 6, 292–295 (20 March 1977)

We report the first observation of acoustic nuclear spin echo excited by acoustic pulses, and electromagnetic echo excited by a combination of electromagnetic and acoustic pulses in antiferromagnets.

PACS numbers: 76.60.Lz, 75.50.Ee

Investigation of acoustic spin echo yields new information, compared with electromagnetic echo, concerning the transition processes in spin systems and on the mechanisms of spin-phonon coupling. Owing to the large experimental difficulties, however, acoustic echo has been observed so far only for the electron spins of Fe^{2+} and Ni^{2+} in MgO, whereas an electromagnetic field excited by a combination of acoustic and electromagnetic pulses was observed for the spins of Fe^{3+} and Mn^{2+} in MgO [1,2] and the nuclear spins of I^{127} in CsI. [3]

There exists a class of substances which differ from dielectrics both in the mechanism whereby the spin echo is produced and in the mechanism of the spin-phonon coupling. [4–8] It is known that hyperfine interaction produces in magnetically ordered crystals a strong coupling between the oscillations of the electron and nuclear spin systems. This coupling manifests itself most distinctly in the NMR dynamic frequency shift. [9]

For nuclei of magnetic atoms, the interaction of the spins with resonant ultrasonic oscillations is effected via spin waves—the magnetoelastic mechanism. The acoustic energy is transferred to the nuclei via periodic deformations of the lattice by the acoustic oscillations. These deformations produce, via the magnetoelastic coupling, oscillations of the electron spins and subsequently act on the nuclear spin system via the hyperfine coupling. For low-anisotropy antiferromagnets, resonant absorption of acoustic energy by nuclear spins exceed by 8—10 orders of magnitude the corresponding coefficients for nonmagnetic nuclei.

The echo waves were observed by a pulse procedure, in which acoustic pulses of duration 0.2 μsec were excited on one surface and detected on the opposite surface of the sample with the aid of lithium-niobate piezoconverters. The pulses passing through the sample were registered with a superheterodyne receiver

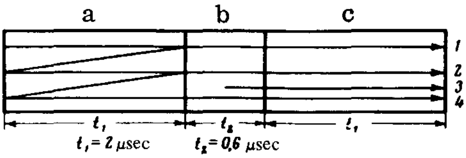

FIG. 1. Passage of acoustic pulses through a sample (b); a and c—the transmitting and receiving piezoconverters.

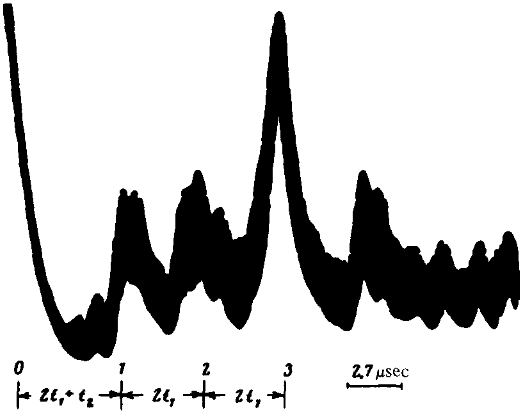

FIG. 2. Acoustic echo signal (3) detected in the second piezoconverter; 1,2—first and second acoustic pulses; 0—electromagnetic pulse exciting the piezoconverter.

having a sensitivity ~ 10^{-44} W. The pulses of the longitudinal acoustic waves propagated along the [100] axis of the cubic crystals $KMnF_3$ and $RbMnF_3$, made in the form of parallelepipeds with plane-parallel ends, measuring $5\times 5\times 3.5$ and $5\times 5\times 3.1$ mm, respectively.[1)] We have observed, for the first time, acoustic or *phonon echo following excitation of the nuclear spin system of* Mn^{55} *in single-*crystal $KMnF_3$ by two acoustic pulses near the nuclear resonance. The first to act on the spin system was an acoustic pulse (1) of duration $\tau \sim 0.2$ μsec (Fig. 1). The second to act, at an interval $2t_1$ following the first, was the acoustic pulse (2) reflected from the front end face of the first converter. In view of the imperfect matching of the converter to the sample, the intensity of the second pulse was 2/3 of the first. The acoustic echo (3) was produced against the background of the third acoustic pulse (4), reflected twice from the front end face of the piezoconverter. When the magnetic field approached the resonance conditions for the Mn^{55} nuclei, the intensity of the acoustic exciting pulses decreased sharply, owing to the increase of the magnetic absorption of the ultrasound in the sample, and correspondingly the echo signal increased sharply (Fig. 2). That the echo is of spin origin is confirmed by the angular dependence of its intensity on H_0.

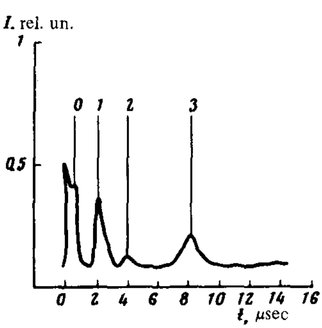

FIG. 3. Electromagnetic echo signal excited by a sequence of electromagnetic and acoustic pulses.

We have also observed electromagnetic spin echo on Mn nuclei in $RbMnF_3$, excited by a sequence of electromagnetic and acoustic pulses with durations 0.3 μsec and with intervals 4 μsec between them. The excitation of the magnetic pulse and the detection of the echo signal were effected by a helical resonator in which the sample was placed. A decoupling of 40 dB between the receiver and the transmitter was produced by a circulator and by a diode switch. The echo signals were produced 4 μsec after the action of the acoustic pulse on the sample. Figure 3 shows the signals received by the helical resonator: 0—electromagnetic pulse, 1—pulse exciting the piezoconverter, 2—electromagnetic pulse excited by the acoustic pulse at the interface between the piezoconverter and the sample, 3—echo signal.

The echo was produced not only when the magnetic field corresponded exactly to the resonance condition, but also at deviations on the order of several hundred gausses. The character of the variation of the echo intensity coincides in the main with the results of observation of the ordinary electromagnetic echo.[5]

A noteworthy characteristic feature of the experimental results is the high intensity of the observed echo signals, apparently a consequence of the strong spin-phonon interaction of the magnetic nuclei in weak-anisotropy antiferromagnets.

[1)]The $RbMnF_3$ crystals were grown by S. V. Petrov at the Institute of Semiconductor Physics, USSR Academy of Sciences.

[1]W. S. Shiren, Phys. Rev. **B2**, 2471 (1970).
[2]D. R. Taylor and I. J. Bartlet, Phys. Rev. Lett. **30**, 96 (1973).
[3]V. A. Golenishchev-Kutuzov, N. K. Solovarov, and V. F. Tarasov, Pis'ma Zh. Eksp. Teor. Fiz. **22**, 266 (1975) [JETP Lett. **22**, 123 (1975)].
[4]J. B. Merry and D. I. Bolef, Phys. Rev. **B4**, 1572 (1971).
[5]M. P. Petrov. G. A. Smolenskiĭ, A. A. Petrov, and S. I. Stepanov, Fiz. Tverd. Tela **15**, 184 (1973) [Sov. Phys. Solid State **15**, 126 (1973)].
[6]S. A. Zel'dovich and A. R. Kessel', Fiz. Tverd. Tela **17**, 3049 (1975) [Sov. Phys. Solid State **17**, 2022 (1975)].
[7]E. A. Turov, M. M. Kurkin, and V. V. Nikolaev, Zh. Eksp. Teor. Fiz. **64**, 283 (1973) [Sov. Phys. JETP **37**, 147 (1973)].
[8]Yu. M. Bun'kov and B. S. Dumesh, Zh. Eksp. Teor. Fiz. **68**, 1161 (1975) [Sov. Phys. JETP **41**, 576 (1975)].
[9]E. A. Turov and M. P. Petrov, YaMR v ferro- i antiferromagnetikakh (NMR in Ferro- and Antiferromagnets) Moscow, Nauka, 1969.