Parametric effect in nuclear spin echo in $FeBO_3$

M. P. Petrov and V. R. Korneev

A. F. Ioffe Physicotechnical Institute, USSR Academy of Sciences
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We observed at 77 K threshold-dependent parametric pumping of a nuclear spin system, parametric echo, and an anomalous dependence of the intensity of the spin echo on the external magnetic field in an $FeBO_3$ single crystal enriched with the Fe^{57}.

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Investigations of the parametric action exerted on a nuclear spin system in magnetically ordered crystals have already been reported.[1-4] An essential circumstance in these investigations was the presence of a large dynamic shift (pulling) of the NMR frequency, due to the interaction of the oscillations of the nuclear and electronic magnetic subsystems. The value of the pulling in the aforementioned papers was 1.5–80% of the resonant frequency. In the interpretation of the results, the larger value of the pulling played the decisive role.

In the present study we observed parametric phenomena in the nuclear spin system of the $FeBO_3$ crystal for the Fe^{57} nuclei at a temperature 77 K. According to

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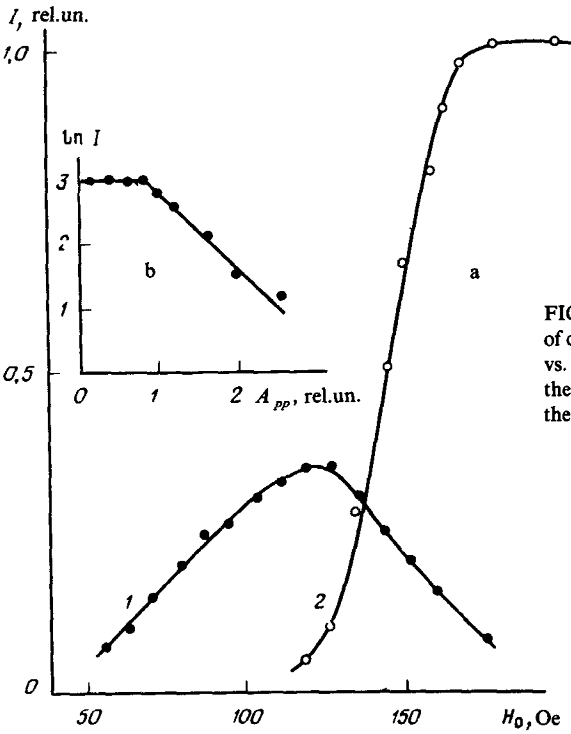

FIG. 1. a) Intensity of parametric echo (1) and of ordinary echo in the presence of pumping (2) vs. the external magnetic field; b) dependence of the natural logarithm of the echo intensity on the pump pulse amplitude.

estimates, the pulling under these conditions is less than $10^{-2}\%$ of the resonant frequency and is not observed directly in experiment.

$FeBO_3$ is a weak ferromagnet (antiferromagnet with canted sublattices) with an anisotropy of the easy plane type. This principal data on the magnetic properties and NMR parameters of $FeBO_3$ are contained in[5].

The investigations presented in the present communication were made on single-crystal $FeBO_3$ samples both with natural content of the isotope Fe^{57} (2.2%) and enriched with Fe^{57} to 85%. The samples were cylinders of 2 mm diameter and 1 mm height. The "c" axis of the crystals coincided with the cylinder axis. The measurements were made with a nuclear-spin-echo setup in the 75.4 MHz band at different values of the external magnetic field. The experiment consisted of applying to the sample not only RF pulses at the NMR frequency but also pump pulses at double the frequency $f_p = 150.8$ MHz, and a study of the influence of the pump on the nuclear-echo signal.

Figure 1(a) shows different plots of the behavior of the echo signal in the presence of pumping. The polarization of the alternating field in the direction of the constant field is shown in the insert of Fig. 2. All the fields lie in the easy plane. We note immediately that all the effects connected with the influence of the pump were observed only in the enriched sample. In addition, it was necessary that the pump-frequency mismatch $\delta f_p = f_p/2 - f_0$ not exceed the width of the spectrum of the radio

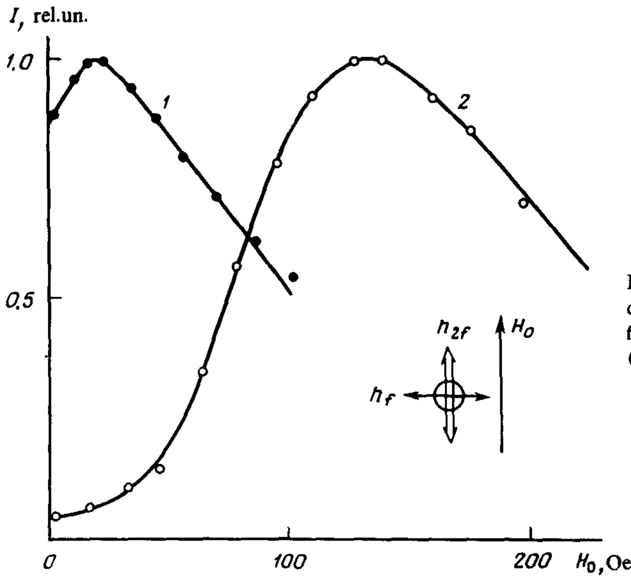

FIG. 2. Dependence of the intensity of the echo on the external magnetic field for unenriched (1) and enriched (2) samples.

pulses making up the echo system (~50–100 kHz). If the pump pulse is applied somewhat earlier (by 0–10^{-1} sec) than the pair of radio pulses forming the echo, then a decrease of the echo signal is observed. This action of the pump on the echo signal is observed when a certain threshold pump-pulse intensity is reached [Fig. 1(b)]. The absolute value of the pump field is determined with low accuracy but it appears that the values of the threshold field do not exceed ~1–3 Oe. The delay time between the pump pulse and the first pulse forming the echo is 500×10^{-6} sec, and the duration is 10×10^{-6} sec.

Curve 2 [Fig. 1(a)] shows the dependence of the echo intensity on the external field for $h_{2f}=4h_{2f}^{\text{thr}}$ at $H_0=120$ Oe and $\tau_{pd}=400\times10^{-6}$ sec. Curve 1 shows the dependence of the intensity of the so called parametric echo. In this case the pump pulse is applied in place of the second pulse that forms the echo. If the intensity of the pump exceeds the threshold value, an echo signal is observed. Replacement of the first pulse by a pump pulse does not lead to the appearance of an echo.

The difference between the echo signals in enriched and unenriched samples is not confined to the pump pulses. In the absence of a pump, different dependences of the relative values of the echo-signal intensity on the external magnetic field were observed for the enriched and unenriched samples (Fig. 2). Attention is called to the anomalous behavior ($I\rightarrow0$) of the echo intensity as $H_0\rightarrow0$. At the same time, for the enriched sample, the dependence has the usual character.[6] We note that the saturation fields in $FeBO_3$ amount according to the data of[6] to ~20 Oe and, when account is taken of the crystal dimensions, they correspond to data obtained by us in the study of the hysteresis loops in our samples. The ratio of the absolute maximum values of the echo intensity for both types of samples corresponds, within the limits of the measurement accuracy, to the number of Fe^{57} nuclei in each of the samples.

Thus, the main results of our experiments are the following. 1. For the enriched sample, an anomalous decrease of the intensity in a zero external field has been observed. 2. A threshold pump effect is observed at exactly double the frequency. 3. A parametric echo is observed if the pump pulse replaces the second forming pulse. 4. No effects connected with pump were observed in the unenriched samples.

As to the interpretation of the results, we can indicate only that the existing models cannot explain the observed effects. For example, estimates of the threshold field of excitation of nuclear spin waves in the model of[2] yield for $FeBO_3$ a value ~ 400 Oe, which exceeds by two orders of magnitude the observed value. An estimate for the gain of the longitudinal radio frequency field, on the basis of the model of[7], yields for $FeBO_3$ a value less than unity, and the parametric-pumping mechanism proposed in[7] has little effect. In this case it is necessary, apparently, to use a different approach to explain the obtained data.

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