Observation of magnetoacoustic echo in paramagnets

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Magnetoacoustic echo was observed in powdered paramagnets $LiTbF_4$, $LiHoF_4$, and $LiErF_4$ at 13.4 MHz and temperature 1.6–4.2°K. The effect is attributed to the presence in the samples of elastic oscillations due to magnetostriction.

In an attempt to investigate, at 13.4 MHz, the nuclear magnetic relaxation in single crystals of $LiTbF_4$, $LiHoF_4$, and $LiErF_4$ it was established that at liquid-helium temperature in the presence of a strong constant magnetic field, damped oscillations are induced in a receiving coil containing the sample following a sounding radio-frequency pulse. Owing to the high intensity and duration of the observation, it was impossible to observe the usual spin echo. A typical picture of these oscillations is shown in Fig. 1a; their intensity is proportional to the constant magnetic field H_0 and is inversely proportional to the temperature, i.e., it is linearly connected with the magnetization of the sample.

In powdered substances, no such oscillations are produced, but when the system is acted upon by two RF pulses at instants of time $t=0$ and $t=\tau$, echo signals are produced at $t=2\tau$, 3τ, and 4τ. A third sounding pulse, separated from the first by an interval T', generates the so-called "stimulated" echo $(T+\tau)$, and also echo signals at the instants $(2T'-3\tau)$, $(2T'-2\tau)$, $(2T'-\tau)$, $(2T')$ and $(2T'+\tau)$. The oscillogram in Fig. 1b illustrates the relative locations and relative intensities of the signals.

The characteristics of the echo signals observed by us in the three substances are very similar; we shall therefore dwell only on the results of the investigation of the compound $LiTbF_4$, which differs from the two others in that its Curie point $T_c=2.86\,°K$ is quite high and falls in a temperature range accessible to us.[1] The properties of the effect can be briefly formulated as follows:

The echo signals are observed only in the presence of a constant magnetic field and have a maximum intensity if the alternating magnetic field H_1 is perpendicular to H_0.

The echo signals are observed in both the ferromagnetic and the paramagnetic phases (up to a temperature $\sim 12\,°K$), their maximum amplitude occuring at the Curie point.

In the paramagnetic region, the echo amplitude is proportional to the ratio H_0/T, i.e., it is proportional to the magnetization of the sample.

The temperature dependences of the echo amplitude in the powder and of the intensity of the stimulated oscillations in single-crystal samples are in good correlation with each other (Fig. 2).

The echo amplitude is proportional to the magnitude of the RF field H_1.

The echo signals have the highest intensity if the sample is in vacuum or in gaseous helium at a pressure lower than 10 Torr; with increasing gas pressure, the signals decrease in amplitude and vanish completely when the sample is immersed in liquid helium.

The characteristic time T_2 obtained from the exponential envelope of the (2τ) echo signals when the interval τ is varied depends on the packing density of the powder. Thus, for unpressed powder consisting of particles ranging from 49 to 55 μ, this time is 25 μsec at 4.2 °K, but when the same powder is compressed at pressures 50 and 150 kg/cm² the times are 14 and 6 μsec, respectively.

The echo signal is maximal if the durations of the

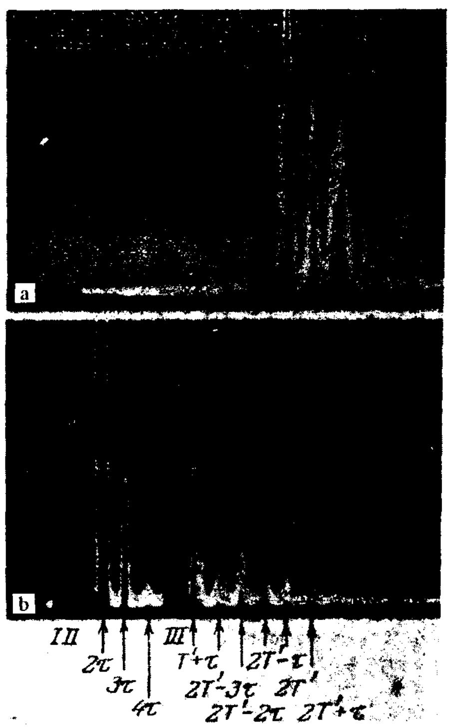

FIG. 1. Oscillograms: a) Stimulated oscillations in single-crystal $LiErF_4$ ($H_0\perp c$, $H_1\perp c$, $H_1\perp H_0$, where c is the crystallographic axis); b) echo signals in $LiTbF_4$ powder (I, II, III—sounding pulses); temperature 4.2 °K, sweep 20 μsec/cm, $H_0=4000$ Oe.

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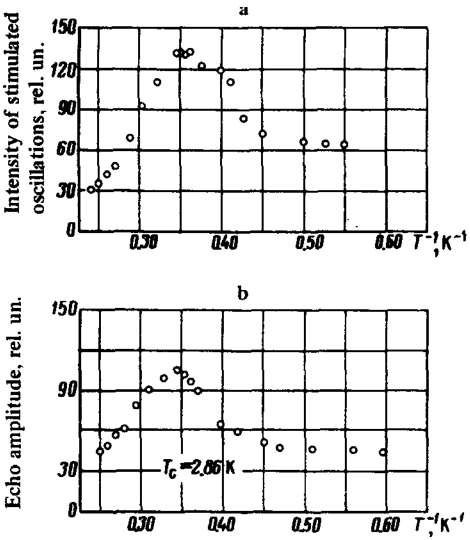

FIG. 2. Temperature dependences of the intensity of the stimulated oscillations in single-crystal $LiTbF_4$ (a) and of the echo signal in $LiTbF_4$ powder (b).

sounding pulses are equal to each other at approximately 3–4 μsec. When the pulse durations are not optimal, the echo becomes asymmetrical and decreases rapidly in amplitude. The optimal durations depend on neither the sample dimensions as a whole nor on the dimensions of the microcrystallites.

The characteristic time T_1 determined from the envelope of the "stimulated" echo signal when the interval T' is varied is close in order of magnitude to T_2.

The foregoing data are similar in many respects with the characteristics of the electroacoustic (phonon) echo, first observed in the radio-frequency band, [2,3] and suggest that we are dealing here with a magnetic analog of this phenomenon. In either case, the existence of echo signals is due to the presence of elastic oscillations in the sample; in our case this is evidenced by the vanishing of the echo when the sample is immersed in liquid helium. In contrast to electroacoustic echo, in our case an important role should be played by spin-spin and spin-phonon interactions, which are quite appreciable in the investigated samples.

We propose that the excitation of the acoustic oscillations in the sample is due to magnetostriction. It is natural to assume that the magnetostriction contribution to the free energy of the paramagnet contains terms that are quadratic in the magnetic field and in the deformation, and that the existence of these terms is the cause of the time "inversion" necessary for the echo production.

We hope that the effect observed by us, that of magnetoacoustic (phonon) echo, affords new possibilities of investigating spin-spin and spin-echo interactions, particularly the little-studied phenomenon of magnetostriction in paramagnets.

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