New mechanism for formation of nuclear spin echo

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A new mechanism for formation of a nuclear echo in magnets, involving a change in the direction of precession of nuclear spins, in predicted theoretically and observed experimentally.

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It is well known that for some ferromagnetic materials the time for pulsed magnetic reversal t_p can be as low as $\sim 10^{-9}$ s, i.e., it is less than the period of precession of nuclear spins. In this situation, the nuclear spins have virtually no time to move within the time t_p. This circumstance was used to create an inversion in the nuclear spin system of ferromagnetic cobalt.[1,2]

In this work, with the help of pulsed magnetic reversal, a new mechanism is

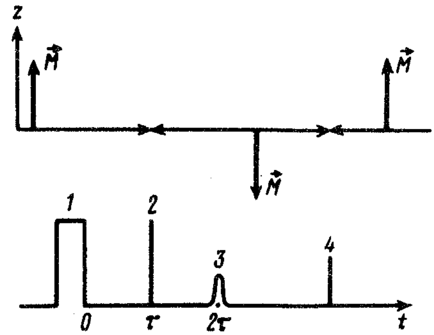

FIG. 1. Temporal diagram showing sequence of pulses. 1—High-frequency pulse; 2—rapid magnetic-reversal pulse; 3—echo signal; 4—return pulse.

realized for formation of a nuclear echo, involving a change in the direction of precession of nuclear isochromates with a change in the orientation of electron magnetization.

The experiments were performed at room temperature. Polycrystalline plates of ferromagnetic cobalt, in which the induced anisotropy field $H_k \approx 30$ Oe, coercive force $H_c \approx 10$ Oe, NMR frequency $\omega_n/2\pi = 218$ MHz, and width of NMR spectrum $\Delta\omega_n/2\pi \simeq 10$ MHz, were used as specimens. The experimental arrangement is shown in Fig. 1.

The specimen is first magnetized along the anisotropy axis, and the nuclear system is initially in an equilibrium state the (nuclear magnetization $\vec{\mu}$ in the equilibrium state is antiparallel to the electronic magnetization **M**). The high-frequency pulse (1) tilts the nuclear magnetization away from the equilibrium position and then, due to the inhomogeneity of the hyperfine fields, the nuclear isochromates dephase; over the time τ, the i-th isochromate with precessional frequency ω_i acquires a phase $\Delta\phi_i = \omega_i \tau$ (the nuclear spins precess counterclockwise). At $t = \tau$, the magnetization of the specimen is reversed over a time $t_p \sim 10^{-9}$ ns. The precessional period of nuclear spins $T \simeq 5 \times 10^{-9}$ s, so that in the first approximation, it may be assumed that the nuclear spins remain in place over the time interval t_p. After the magnetization reversal, the direction of the hyperfine field changes to the opposite orientation; the direction of precession of nuclear isochromates also changes, so that for $t > \tau$, we have $\Delta\phi_i = \omega_i \tau' - \omega_i (t - \tau)$.

Thus, at $t = 2\tau$, $\Delta\phi_i = 0$ for all isochromates simultaneously and an echo signal, which we call an inverse echo, is observed.

After this, a magnetic-reversal pulse (4), which returns the electronic magnetization to the initial state, acts on the specimen. Then, over the time of the order of the longitudinal relaxation time T_1, the nuclear system likewise returns to the starting state. Of course, the repetition period of the echos must greatly exceed T_1.

The dependence of the amplitude of the inverse echo A on the rate of growth of the magnetic-reversal field $\dot{H}$ is shown in Fig. 2a (the value of $\dot{H}$ at which the inverse echo signal appears is chosen as the unit along the abscissa axis in Figs. 2a and 2b).

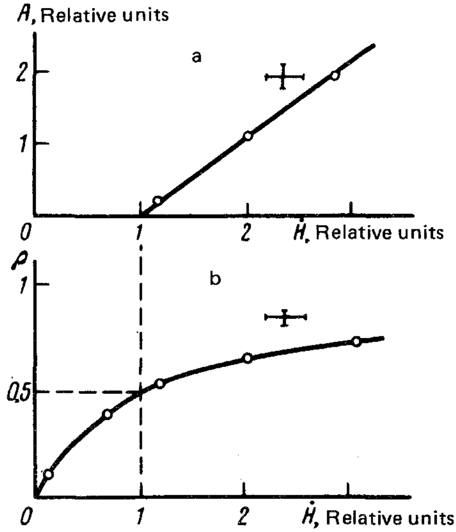

FIG. 2. Dependence of echo amplitude (a) and relative inversion 2a (b) on the rate of growth of the magnetic-reversal field.

The dependence of the relative inversion ρ on $\dot{H}$, measured using the scheme described previously in Ref. 2, is shown for comparison in Fig. 2b. It is evident that the inverse echo is observed at the same rates $\dot{H}$ at which the inversion $\rho > 0.5$ of the nuclear spin system is attained.

[1]V. A. Ignatchenko and Yu. A. Kudenko, Izv. Akad. Nauk SSSR, Ser. Fiz. **30**, 933 (1966).
[2]N. M. Salanskiĭ, I. A. Lyapunov, and V. K. Mal'tsev, Pis'ma Zh. Eksp. Teor. Fiz. **13**, 694 (1971) [JETP Lett. **13**, 491 (1971)].

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