Dependence of conduction-electron spin-echo signals on the exciting-pulse power

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The previously predicted anomalous dependence of the electron echo signals on the amplitude of the radio-frequency field in bulk metal has been experimentally observed.

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It is well known that the magnitude of the spin-echo signal in a dielectric paramagnet is a periodic function of the amplitude of the alternating field H_1 of the exciting pulses (see, e.g., [1]). For the principal echo this dependence takes the form

$$V(H_1) = \frac{1}{2} \mu_0 \sin \gamma H_1' t_1 \sin^2 \frac{\gamma H_1'' t_2}{2}, \qquad (1)$$

where H_1', t_1 and H_1'', t_2 are the field amplitude and duration of the first and second pulses, respectively, γ is the gyromagnetic ratio of the paramagnetic center, and μ_0 is the equilibrium magnetization of the electron. The peculiarity of the transient processes in the spin system of the conduction electrons is brought about by the presence of the skin effect in metals and by the high mobility of the paramagnetic centers. A theory of spin echo and free induction of electrons in bulk metals was recently constructed in[2]. It was shown, in particular, that for spin echo of conduction electrons (SECE) the periodic dependence (1), which is characteristic of dielectrics, is valid only for metallic samples with small dimensions $d \lesssim \delta$ (where δ is the depth of the skin layer). On the other hand in the case of "bulky" samples, when $d^2 \gtrsim 2Dt_i$ (where D is the electron-diffusion coefficient and t_i is the duration of the exciting pulse), the dependence of the SECE signal on the amplitude of the alternating magnetic field is described by a nonperiodic function with one maximum (see the figure):

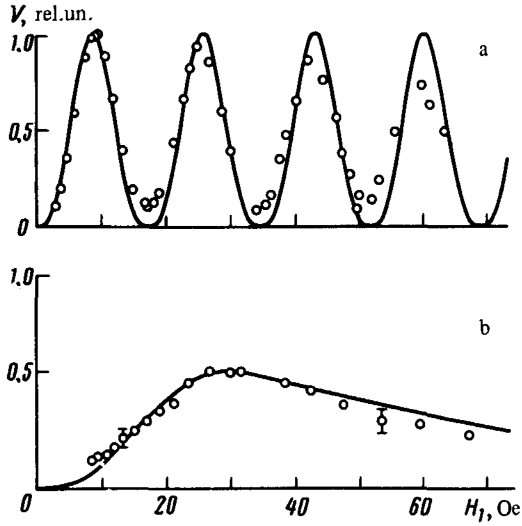

FIG. SECE signal vs the alternating-field amplitude H_1: a) circles—experimental data for a sample with $d=(1-2)\times10^{-4}$ cm, solid curve—theoretical dependence corresponding to the modulus of expression (1); b) circles—experimental data for a sample with $d=(15-20)\times10^{-4}$ cm, curve—theoretical plot corresponding to (2).

$$V(H_1) = \frac{1}{2}\mu_0 \frac{D}{\gamma^2 H_1' H_1'' d^2 \delta^2}\left[\exp\left\{-\frac{\gamma^2 H_1'^2 \delta^2}{D} t_1\right\} - 1\right] \times \left[\frac{2}{\sqrt{\pi}}\frac{\gamma H_1'' \delta}{\sqrt{D}}\sqrt{t_2} + i\,\Phi\left(i\frac{\gamma H_1''\delta}{\sqrt{D}}\sqrt{t_2}\right)\exp\left\{-\frac{\gamma^2 H_1''^2 \delta^2}{D} t_2\right\}\right], \quad (2)$$

where $\Phi(x)$ is the error integral.

In the present study we investigated experimentally the SECE in samples of metallic lithium at an alternating microwave-pulse power. The measurements were made with a 3-cm relaxometer of the type described in[3] with maximum pulse power up to 5 kW. The echo was excited by a series of two pulses of duration 20 and 40 nsec. The measurements were made on two spheroidal metal chunks suspended in a hermetically sealed LiF container. The average particle dimensions in one sample was ~1—2 μ, and in the other ~15—20 μ. This corresponded to the referred-to "small" and "bulky" samples. Indeed, under the conditions of our experiment and at an electron diffusion coefficient in lithium $D\approx 15$ cm^2/sec,[4] the characteristic dimensions are $\delta\approx 1.6\ \mu$ and $\sqrt{2Dt_i}\approx 10\ \mu$. The sample with small particle dimensions was obtained by irradiating a pure LiF single crystal with thermal neutrons in a reactor (radiation dose ~10^{19} neut/cm^2), while the sample with the large particles was obtained by high-temperature electrolysis in the solid phase.[4,5] After the radiolysis and electrolysis, the LiF crystals with the metallic inclusions produced in them were subjected to thermal annealing in order to homogenize the shape and increase the dimensions of the lithium particles. The use of this technique was dictated by the need for obtaining metallic samples of very high purity, with which it is possible to observe reliably the SECE signals. The experimental results obtained from measurements of the dependence of the echo signal on the amplitude of the alternating magnetic field for both samples are summed in the figure. The figure shows also the theoretical plots corresponding to expressions (1)[2)] and (2).

As seen from Fig. a, a periodic dependence of the SECE signal on H_1 is distinctly less for the sample with $d \sim \delta$ (the small decrease of the oscillation amplitude V with increasing H_1 is due to the decreased matching of the microwave channel of the relaxometer at different power levels). The magnitude of the period agrees with the theory within the limits of experimental error.

The measurement data for the sample with $d \gtrsim \sqrt{2Dt_i}$ are shown in Fig. b. The theoretical curve corresponding to expression (2) was plotted for the values $D \approx 15$ cm^2/sec and $\delta = 1.6 \times 10^{-4}$ cm. The results presented in Fig. b offer evidence of quantitative agreement between theory and experiment and thus, confirm the existence of the anomalous dependence of the SECE signals on the microwave-field amplitude in bulk metal.

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[2)]Taking into account the fact that we used a relaxometer based on an incoherent detection scheme, the theoretical plot shown in Fig. a corresponds in fact to the modulus of expression (1).

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