of the fitting. The curves corresponding to fitting at n = 2 and n = 1 are shown in Fig. 2 by solid and dashed lines, and differ insignificantly from one another. To choose the concrete value of n, measurements at large k^2 are necessary.

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NEW EFFECTS IN THE ABSORPTION OF ULTRASOUND IN THE INTERMEDIATE STATE OF A VERY PURE SUPERCONDUCTOR

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The oscillatory absorption of ultrasound (US) in the intermediate state (IS) of a superconductor of the first kind [2] (upon change in thickness of the normal layers a with change of magnetic field H), which was theoretically predicted by Andreev [1], cannot be observed without overcoming the difficulties involved in the production [3] of a periodic structure of the IS in the interior of the metal and satisfying a number of strong inequalities relating the electron mean free path ℓ, a, and D_{ext}[1)], namely $\ell \gg D_{ext} \gg a$. The criterion for satisfying the most stringent condition $\ell \gg D_{ext}$ (the field H exerts a definite influence on the dynamics of the electrons in the normal layers) is the process of ordinary magnetoacoustic oscillations in the normal state of the metal at $T > T_c$ and $H < H_c$. The only superconductor in which one can certainly hope to observe the predicted phenomenon is pure gallium, in which magnetoacoustic oscillations were observed in the normal state [4] in fields starting with several Oersted.

1. We present below some results obtained in an investigation, by a pulsed method [5] of the absorption of longitudinal ultrasound of frequency

[1)] A.F. Andreev advised us that in the formulas of [1] R_{ext} should be taken to mean the extremal diameter D_{ext} of the electron orbit in the magnetic field.

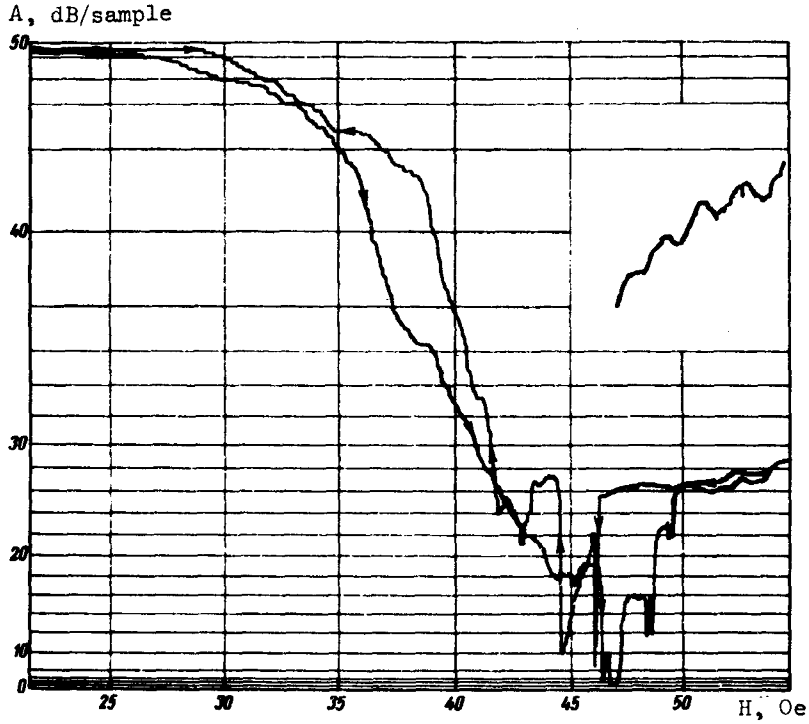

Fig. 1. Plot of the amplitude A(H) of the transmitted ultrasound in the S-N and N-S transitions of gallium in the intermediate state at T = 0.39°K, obtained with a PDS-021 automatic recorder; ultrasound frequency f = 130 MHz, $\vec{k} \perp \vec{H}$, $\vec{k} \parallel \vec{b}$, $<\vec{H},\vec{c}$ = 22°. The rate of change of H is 0.75 Oe/min. The insert shows a plot of A(H) in the normal state of gallium at increased sensitivity of the PDS-021 recorder.

50 - 190 MHz in the intermediate state of pure gallium[2]. Measurements at temperatures down to 0.32°K were carried out in a cryostat using absorption pumping-off of the vapor of ~25 cm^3 of liquid He^3 [6]. The object of the detailed investigation was a cylinder of 7 mm diameter and 21 mm length, cut by the electric-spark method from a single crystal of extremely pure gallium produced by the Giredmet Experimental Plant. The axis of the cylinder coincided with the crystallographic axis $\vec{b}$ of the gallium and with the direction of $\vec{k}$ of the ultrasound[3]. The absorption function Γ(H) was measured by a relative method (by comparing the investigated sample with a standard pulse - for details see [5]) and with automatic plotting on the PDS-021 x-y recorder. The converters of the high-frequency radiation into ultrasound (and vice-versa) were plates of X-cut quartz of thickness ~0.3 mm and diameter 4.5 mm; a monochromatic beam of longitudinal ultrasound passed, without touching the side surfaces, along the central region of the sample[4]. The intermediate state in the sample was produced by a homogeneous transverse magnetic field from a pair of Helmholtz coils ($\vec{H} \perp \vec{k}$). The vector $\vec{H}$ could be rotated in the plane of the axes a and c of the gallium, which was perpendicular to the axis of the sample, at a rate of 1 rpm. The stabilization of H (and when necessary its linear variation) was by means of a stabilization and field-sweep scheme [7], the

[2]) In our samples, at $\vec{k} \perp \vec{H}$, the magnetoacoustic oscillations in the normal state of the gallium at $T > T_c$ and at the lowest employed ultrasound frequency 50 MHz was observed starting with fields H ≈ 3 Oe ($\vec{k}$ - wave vector of the ultrasound).

[3]) The authors wish to thank once more E.A. Levikov and L.V. Levikova for precision orientation of the samples with the aid of a beam of x-rays converging in a solid angle.

[4]) The authors are grateful to A.I. Shal'nikov and V.G. Bar'yakhtar for supplying the "No-nag" lubricant, with which acoustic contact was made between the sample and the quartz plates.

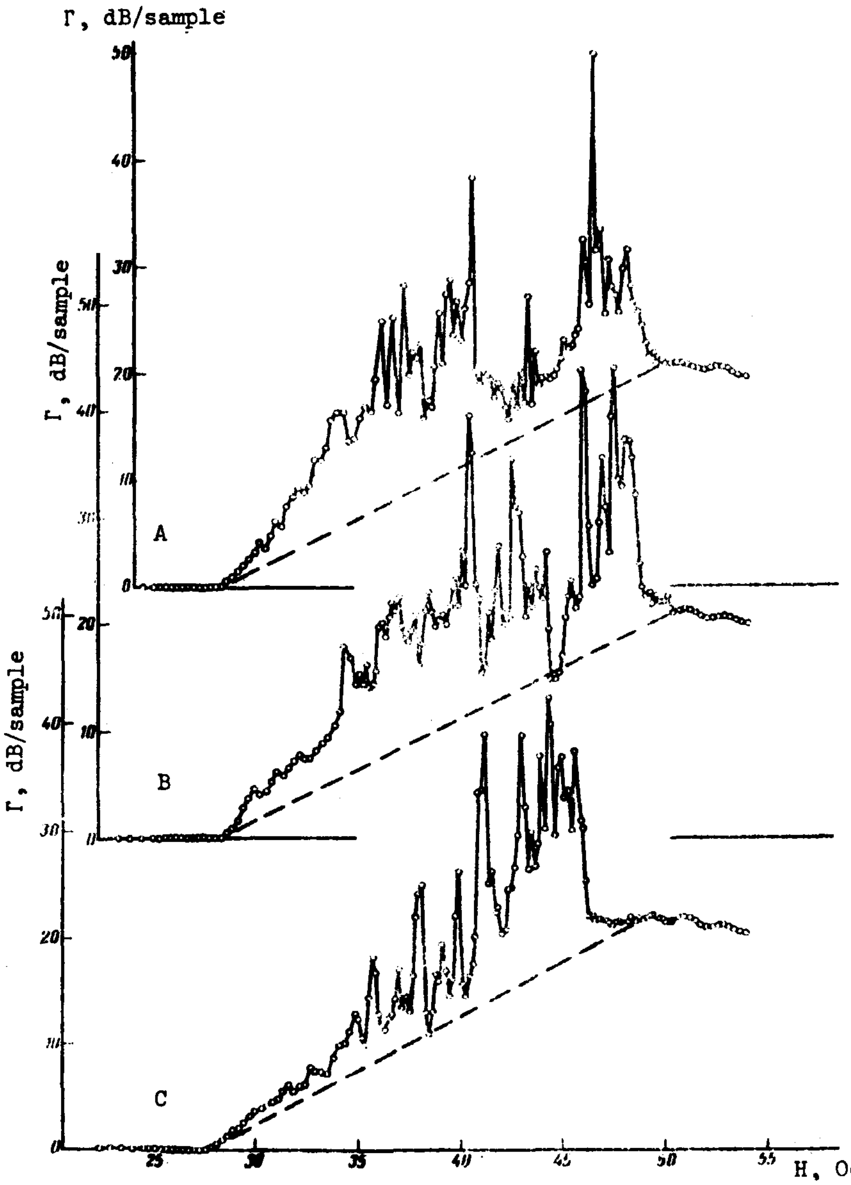

Fig. 2. Dependence of the ultrasound absorption Γ(H) in the intermediate state of gallium: A - after one revolution of $\vec{H}$ between neighboring points in the S-N transition, B - after two revolutions of $\vec{H}$ in the S-N transition, C - after two revolutions of $\vec{H}$ in the N-S transition. f = 130 MHz, $\vec{k} \perp \vec{H}$, $\vec{k} \parallel \vec{b}$, $<\vec{H},\vec{c} = 22°$. The time of each measurement exceeds 5 hrs, the temperature is close to 0.4°K. The dashed lines represent the monotonic part of (H) at ka >> 1 in accordance with the theory of [1].

stabilization accuracy of which was better than 3×10^{-4}. During the course of the measurements the sample was in direct contact with the liquid He^3, and the earth's magnetic field was compensated by means of two pairs of Helmholtz coils.

2. In the experiment we determined the Γ(H) dependence in gallium at constant temperature. Figure 1 shows the plots obtained with the automatic recorder PDS-021 on going from the superconducting (S) to the normal (N) state and back; each of the plots took 45 min to produce. Large oscillations of Γ in the intermediate state of gallium are observed at $H \leq H_c$ in all the measurements, independent of the ultrasound frequency and of its amplitude at temperatures 0.37 - 0.75°K. In view of the high purity of the gallium, hysteresis phenomena are observed - superheat (in the S-N transition) and supercooling (in the N-S transition). However, the magnitude of the ultrasound absorption (even at the fastest rate of change of the field, 17 Oe/min), is reversible

with accuracy 0.2 dB/sample in the S-N transition and back, thus evidencing the absence of a "frozen-in" flux.

To obtain intermediate-state structures close to equilibrium [2], we used slow rotation of H between points separated by an amount $\Delta H \simeq 0.003 H_c$. At a smooth variation of H (rate 0.7 Oe/min) the vector $\vec{H}$ executed several complete revolutions about the axis of the sample at a rate of 1 rpm. It turned out that a very complicated oscillatory $\Gamma(H)$ dependence is obtained even after one revolution of $\vec{H}$ (Fig. 2a). Since the value of Γ at each point after a change ΔH in H does not depend on the time, it can be assumed that the produced structure is close to equilibrium and has, in accordance with the theory [2], a layered disk-like shape. This is all the more correct since the shapes of the $\Gamma(H)$ curves after one and two revolutions of $\vec{H}$ (see Fig. 2) are similar, and the value of Γ at each point after two revolutions is practically independent of the number of revolutions[5)]. The intermediate-state regions with small and large concentrations of the N phase are of interest, since they apparently contain isolated filaments of N and S phases, respectively, and there is no periodicity of the structure. The fact that the magnetic field in the normal layers H_c does not change with variation of H leads to the vanishing of the usual magnetoacoustic oscillations in the N-S transition. This is one more proof that the observed effect cannot be due to the usual oscillatory phenomena existing in the normal metal. The obtained results differ significantly from the data of earlier ultrasonic investigations of the intermediate state of superconductors (see the review [9])[6)]. Although the picture of the phenomenon is complicated, the scale of the effect is striking, for the magnitude of certain oscillations exceeds the total electronic ultrasound absorption Γ_0 in the normal metal at $H = H_c$! As shown by a computer calculation, at ka $\sim$ 3 - 30 and $a/D_{ext} \sim 0.1 - 0.9$, the scale of the real phenomenon is well described by the theory[7)]. It is necessary to take into account here the fact that the experimental results may differ from the predictions of the theory, since the theory employed a model of the metal with a very simple Fermi surface. The object of the investigation, gallium, has a complicated Fermi surface [12], and the phenomenon can apparently be the result of a superposition of several D_{ext} (in the investigated case, two). In this connection, theoretical calculations are necessary, with account taken of the observed experimental

[5)]Walton [8], in an earlier study of the thermal conductivity, reached a similar conclusion concerning the role of the rotation (at a rate ~0.1 rpm) in the formation of the equilibrium structures of the intermediate state of tin.

[6)]Observation of a nonmonotonic $\Gamma(H)$ dependence at ultrasound frequency 19.5 MHz in the intermediate state of tin was reported [10]. However, the $\Gamma(H)$ dependence obtained there contains no oscillations, owing to the fact that the condition $L \gg D_{ext}$ was not satisfied, since in fields $H \leq H_c$ at the indicated ultrasound frequency the usual magnetoacoustic oscillations are not observed [11]: $D_{ext} = 1.3 \times 10^{-1} - 3.2 \times 10^{-2}$ cm at the investigated [10] values of H_c of tin, and $\ell \simeq 3 \times 10^{-2}$ cm. The nonmonotonicities of [10] are the results of a complicated recalculation using the temperature dependences of several physical quantities, obtained for different samples by different authors, and lie within the limits of the measurement and calculation accuracy.

[7)]The authors are grateful to L.G. Shepeleva for help with the programming and with the calculations on the "Minsk-22" computer.

interference picture of the phenomenon[8]. The dimension a in the interior of the metal at large concentrations of the N phase, estimated from the periodicity of the Γ(H) oscillations, using the Landau non-branched model of the intermediate state [2], amounts to a $\sim 10^{-2}$ cm.

3. Besides the obtained Γ(H) oscillations, we obtained experimentally a maximum of the monotonic absorption of longitudinal ultrasound in the intermediate state of the very pure superconductor. The nature of this phenomenon is not clear, but the fact that the absorption in the intermediate state is many times larger than the absorption in the normal state of the metal (and is larger than the absorption corresponding to the theory of [1] at $ka \gg 1$ (see Figs. 1 and 2)) is evidence of the strength of the mechanism causing this phenomenon. One of the probable mechanisms, namely vibration of the interphase boundaries [13], cannot give seemingly so large a contribution to the absorption; to be sure, the theoretical calculations [13] were performed for lower ultrasound frequencies (10^6 - 10^7 Hz) and for $\ell \ll a$. It is possible that its contribution is appreciable under our extremal conditions ($ka \gg 1$ and $\ell \gg a$).

Detailed measurements of the dependence of $\Gamma(\vec{H})$ in the intermediate state of gallium on the temperature, the orientations of $\vec{k}$ and $\vec{H}$ relative to the crystallographic axes and relative to each other, and on the ultrasound frequency will be reported in a detailed communication.

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