DISPERSION OF SOUND VELOCITY IN GALLIUM IN STRONG MAGNETIC FIELDS

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As first noted by Kulik [1], an appreciable (10 - 20%) change of the longitudinal-sound velocity should be observed in metals, assuming a quadratic dispersion law at $\omega\tau \geq 1$, $\vec{q} \perp \vec{H}$, in strong magnetic field such that $qr_H \ll 1$. Here ω and q are respectively the requency and the wave vector of the sound, r_H the electron-orbit radius in the magnetic field H, and τ the electron relaxation time. This effect is connected with the fact that the dispersion of the longitudinal phonons is determined to a considerable degree by the screening action of the electron gas [2 - 4].

The influence of the magnetic field on the change of the longitudinal-sound velocity can be qualitatively explained as follows: In the approximation of the simple Hartree theory of dielectric screening and of the jelly model, the dispersion of the longitudinal phonons is given by the well known Bohm-Staver formula

$$\omega^2(q) = \Omega_p^2/\varepsilon(q),$$

where Ω_p is the plasma frequency of the lattice ions and $\varepsilon(q)$ is the dielectric constant of the metal. In the presence of magnetic field, the character of the variation of the longitudinal-sound velocity in the metal is determined by the behavior of the component of the tensor $\varepsilon_{ll}(\vec{q}, \omega, \vec{H})$ along the sound-propagation direction. As follows from [5, 6], when $\omega\tau \gg 1$ and $\vec{q} \perp \vec{H}$, an anomalously large change of ε_{ll} takes place in a strong magnetic field when $qr_H \ll 1$, and the longitudinal-sound velocity changes accordingly.

It must be noted that in the approximation where $\omega\tau \to \infty$ and $\beta = 0$ (β - ratio of skin-layer depth in metal to the wavelength of the sound) the main results of [1] agree fully with the results obtained in [5]. According to these papers, the relative change of the longitudinal sound velocity is determined when $\vec{q} \perp \vec{H}$ by the expression

$$\frac{\Delta S}{S} = \frac{z m\omega^2 r^2 v_F^2}{6MS^2(1 + \omega^2\tau^2)} f(qr_H),$$

where z is the number of valence electrons, v_F the electron Fermi velocity, M the metal ion mass, and $f(qr_H)$ a function characterizing the change $\Delta S/S$ in a magnetic field and having the following limiting values: $f(0) = 0.2$ and $f(\infty) = 0$.

The presently available experimental data on the change of the longitudinal-sound velocity in metals in magnetic fields yield a value of $\Delta S/S$ smaller by several orders of magnitude than the maximal value (10 - 20%) obtained in [1]. For aluminum [7] at $\omega\tau \sim 10^{-2}$, $qr_H \ll 1$, and $\vec{q} \perp \vec{H}$, the change of the sound velocity amounted to 5×10^{-5}. The strong-field condition was not satisfied in [8]. The maximum value of $\Delta S/S$ at $\omega\tau \sim 1/3$ and $qr_H \sim 1$ was about 2 x

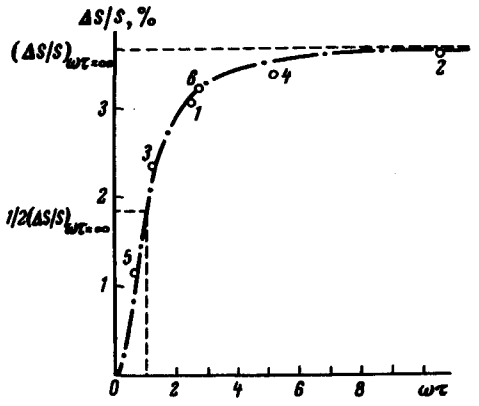

Fig. 1. Dash-dot line - $f(\omega\tau) = (\Delta S/S)_{\omega\tau=\infty} \times (\omega\tau)^2/[1+(\omega\tau)^2]$. Points: 1) 200 MHz, T = 4.2°K; 2) 200 MHz, 1.6°K; 3) 100 MHz, 4.2°K; 4) 100 MHz, 1.6°K; 5) 50 MHz, 4.2°K; 6) 50 MHz, 1.6°K.

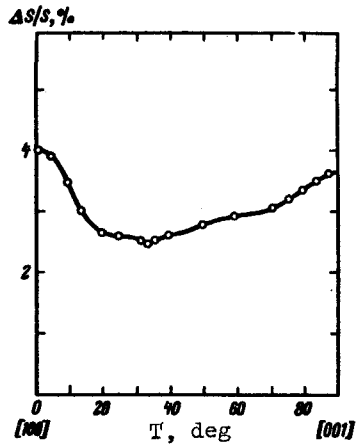

Fig. 2

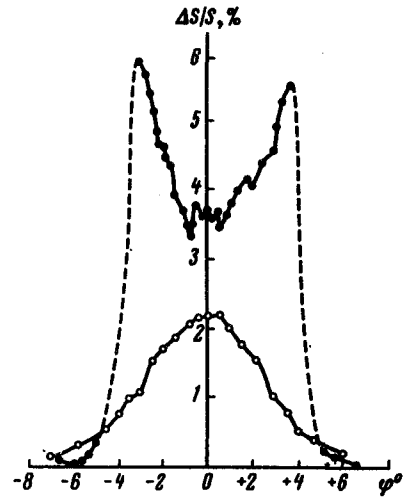

Fig. 3. The full and light circles correspond to $\omega\tau = 10.4$ and $\omega\tau = 1.2$.

10^{-4} for Cd and 8×10^{-4} for Cu.

We attempted to observe the effect of appreciable change in the longitudinal-sound velocity. The investigation was moade on Ga, for which the condition $\omega\tau \geq 1$ can be satisfied even at sufficiently low ultrasound frequencies. The Ga samples were cylinders 11 mm in diameter and 1 - 2 mm thick. The cylinder axis was close to the [010] direction and coincided with the $\vec{q}$ direction. The sample could be rotated relative to the $\vec{H}$ direction in such a way as to leave $\vec{H}$ in the (010) plane. The system for inclining the sample has made it possible to vary smoothly the angle ϕ of deviation of $\vec{q}$ and $\vec{H}$ from $\pi/2$. The measurements were made at 50, 100, and 200 MHz; the sample temperature was varied between 4.2 and 1.6°K by pumping off He vapor.

Figure 1 shows a plot of $\Delta S/S$ vs. $\omega\tau$ for $H \parallel [001]$ and $qr_H \ll 1$, obtained in the following manner: The points 5, 3, and 1 correspond to $\Delta S/S$ at 50, 100, and 200 MHz respectively and T = 4.2°K. To determine points 6, 4, and 2, corresponding to the same frequencies but at T = 1.6°K, it was necessary to know the factor by which the relaxation time increases upon pumping. The ratio $\tau(1.6°K)/\tau(4.2°K)$ was determined at 50 MHz, using the fact that points 5, 3, and 1 fit well on the theoretical curve [5]. Assuming that the point 6 lies on the same curve, we get $\tau(1.6°K)/\tau(4.2°K) = 4.3$.

The $\omega\tau$ scale is determinedfrom the relation $(\Delta S/S)_{\omega\tau=1} = 0.5(\Delta S/S)_{\omega\tau\to\infty}$, which follows from [5]. The maximum value of $\omega\tau$ obtained in this manner at $\omega/2\pi = 200$ MHz and T = 1.6°K was 10.4. We see that, in full agreement with [1, 5], $\Delta S/S$ is subject to saturation, giving grounds for assuming that the maximum value of $\Delta S/S$ measured in the experiment is close to $(\Delta S/S)_{\omega\tau\to\infty}$.

A tentative plot of $\Delta S/S$ at $\omega\tau = 10.4$ and $qr_H \ll 1$ is shown in Fig. 2. When the direction of H in the (010) plane changes from parallel to [100] to parallel to [001], $\Delta S/S$ changes from 2.5 to 4%, whereas in the approximation of isotropic quadratic dispersion for Ga we have $\Delta S/S \approx 15\%$. Such a discrepancy is connected apparently with the fact that the real electronic

structure of Ga is complicated and its dispersion differs from quadratic.

Notice should be taken, in conclusion, of the slight variation of $\Delta S/S$ in a rather wide range of angles ϕ, whereas according to [1] a sharp decrease of $\Delta S/S$ should occur already when ϕ is several times larger than S/v_F, i.e., at angles close to 1°. The experimentally obtained dependence of $\Delta S/S$ on ϕ at $qr_H \ll 1$ is shown in Fig. 3. We see that when $\omega\tau = 10.4$ the value of $\Delta S/S$ not only fails to decrease, but even increases in the region of angles ϕ up to 4°, and experiences a number of extrema. Additional experiments are being planned for the purpose of explaining the observed relations.

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INVESTIGATION OF THE DOMAIN STRUCTURE OF SILICON IRON WITH THE AID OF POLARIZED NEUTRONS

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Various authors have considered, with varying degrees of approximation, the connection between neutron depolarization in a transmitted beam, the domain dimensions, and the saturation induction [1 - 3]. These investigations have made it possible to estimate the average domain parameters, but no account was taken of the influence of the domain structure as a whole on the character of the passage of the polarized neutrons. With an aim at a more thorough study of the domain structure, we set up experiments on the influence of the magnetic field and temperature on the neutron depolarization. The investigation objects were iron single crystals measuring 1.1 x 1.8 x 0.047 cm. Three types of plates were investigated, with the [100] direction along the largest side and at angles 45° and 90° to it. The plane of the plate coincides with the (110) plane within 1 - 2 degrees. The sample was made up of 11 plates. The sample was annealed in vacuum at 1100°C for 24 hours. The measurements were made with the polarized-neutron spectrometer described earlier in [4]. The beam parameters were $\lambda = 1.13$ Å and $P_1P_2 = 0.952$, where λ is the neutron wavelength and P_1 and P_2 the polarization efficiencies of the analyzer and polarizer crystals, respectively. We determined the dependence of the polarization ratio R on the applied magnetic field and temperature. R was defined as the ratio of the neutron-beam intensity without turning on the non-adiabatic neutron spin flip to the intensity with the spin-flip turned on. The plates were oriented with the largest side parallel to the field. The measurement results are shown in Figs. 1 and 2. It must be noted that the character of the depolarization depends on the angle between the [100] direction and the magnetic-field direction, and on the temperature, and also that it has a resonant dependence on the magnitude of the magnetic field. No such resonances were observed in samples made of polycrystalline iron plates. To determine the nature of the observed resonances, we