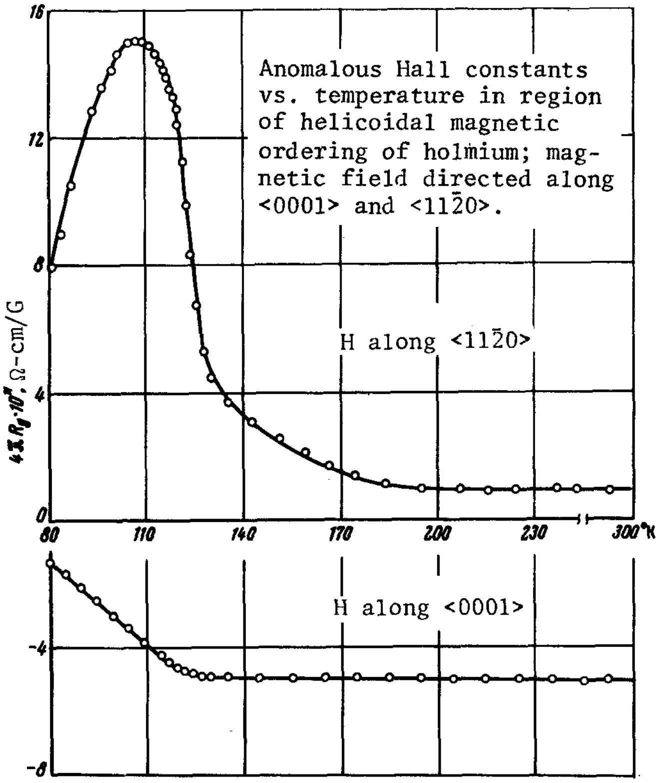

Anomalous Hall constants vs. temperature in region of helicoidal magnetic ordering of holmium; magnetic field directed along <0001> and <11$\bar{2}$0>.

The figure shows the temperature dependences of the aforementioned constants near the Neel temperature $T_N = 125°K$. It is seen that the helicoidal magnetic structure of the holmium, which leads in accord with the theory to the appearance of new Brillouin-zone boundaries and to the distortion of the Fermi surface, becomes strongly manifest in the temperature dependence of the Hall constants. The constant R_g(H along <0001>) varies linearly with the temperature in the helicoidal region near T_N, and is independent of the temperature in the paramagnetic region. The regularity observed for R_g shows unequivocally that this constant is determined by the scattering of the conduction electrons by inhomogeneities of the spin system, a scattering that does not depend on the temperature above T_N and decreases in proportion to $(T_N - T)$ below T_N. Thus, the constant R_g(H along <0001>) is described in the helicoidal region by the relation $R_g = (R_g)_{T>T_N} + C(T_N - T)$, where C is a constant independent of the temperature $(C > 0)$, $(R_g)_{T>T_N} < 0$.

A more complicated temperature dependence is observed for the helicoidal Hall constant R_g when the magnetic field is directed along <11$\bar{2}$0>. In the paramagnetic temperature region, R_g is independent of the temperature, just as in the case when H is directed along <0001>. However, if a magnetic superstructure exists in holmium below T_N then an essential singularity is observed in the temperature dependence of R_g(H along <11$\bar{2}$0>), connected with the sharp growth of this constant near T_N. It might seem that the constant R_g(H along 11$\bar{2}$0) should decrease as a result of the decrease in the scattering by the spin inhomogeneities below T_N, just as in the case of R_g(H along <0001>). The observed growth of R_g(H along <11$\bar{2}$0>) is due to the presence of energy gaps in the conduction-electron spectrum. These gaps lead to an anomalous increase of the magnetic component of the electric resistance, and by the same token to an anomalous increase of the Hall resistance in this direction.

Thus, the helicoidal magnetic structure of holmium, which leads to the appearance of new Brillouin-zone boundaries and to deformation of the Fermi surface, is indeed strongly manifest in the temperature dependence of the helicoidal Hall constants.

JUMPS OF THE RADIOELECTRIC CURRENT IN BISMUTH

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A jump was seen to appear on the oscillogram of the radioelectric effect in bismuth (4.2°K) in the presence of a constant magnetic field when the threshold value of the microwave power was reached.

Much attention is being paid presently to theoretical investigations [1 - 4] of the contributions of various nonlinearity mechanisms to the radioelectric effect (REE)$^{1)}$. We have attempted to study the time evolution of the REE in single-crystal bismuth at 4.2° in the presence of a constant magnetic field (H_0). Unlike experiments carried out in the stationary regime [5, 6], we used a pulse technique (τ_p = 2 - 10 μsec). This enabled us to increase appreciably the power P (in the pulse) without causing an average temperature rise.

A sample in the form of a disk (1.8 cm diam, thickness $d = 0.2$ cm) was grown in a dismountable mold [6] from brand Bi-0000 stock. The sample served as the end wall of a rectangular copper TE_{101} cavity matched to a waveguide at $H_0 = 0$. The maximum alternating field H on the sample reached 50 Oe, which called for a power on the order of 3 kW at $Q = 2000$. The REE signal was picked off a coil and contacts. The coil (20 turns, dimension $\sim$ 1 cm) was placed near the sample outside the cavity, and the contacts were either clamped to a generatrix of the disk (sample 1) or welded to the outer side of the bismuth (sample 2). The REE voltage at the welded contacts reached several volts, and the voltage induced in the coil was several dozen millivolts. Figure 1 (frames 1 - 6) show typical oscillograms. The REE signal is the lower trace in all the frames. The upper trace in frames 1 - 4 is the REE derivative signal picked off the coil, and in frames 5 and 6 it represents the pulse of the microwave generator (from the detector). Oscillograms 1 — 4 pertain to sample 1 oriented with C_3 almost normal (7°) to the surface and C_2 parallel to E along the measured REE (E is the microwave field component tangential to the sample). Sample 2 is obviously oriented.

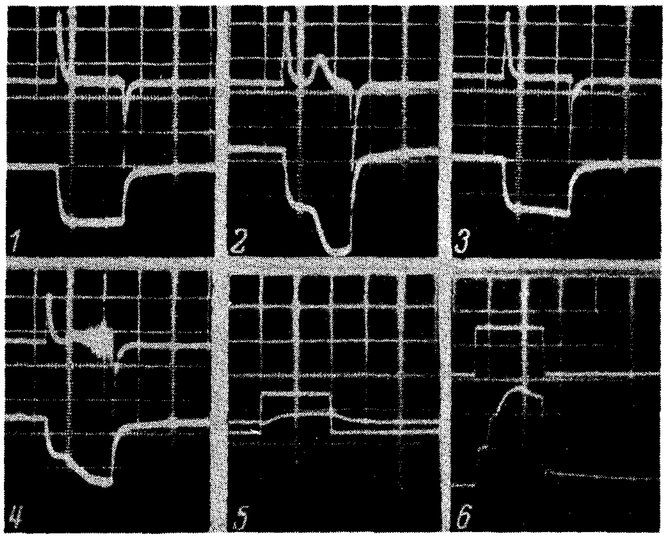

Fig. 1. REE oscillograms at different values of H_0. Each small division on the abscissa axis equals 0.5 μsec.

Frame 1 was taken in a relatively weak magnetic field ($H \sim 4$ kOe). The REE signal almost duplicates the waveform of the microwave pulse. A certain "lag" of the REE is observed and is seen clearly in frames 5 ($H_0 \sim 50$ Oe) and 6 ($H_0 \sim 6$ kOe). With increasing H_0, the signal becomes quite distorted (frame 2). A jump appears, the starting point of which (τ) (in microseconds) lags somewhat the start of the REE pulse. The $\tau(H_0)$ dependence is not monotonic. The numbers 1 and 2 (see frame 2) and 3 (see frame 4) in Fig. 2 mark the three regions where the jump is sharply pronounced. The jump amplitude decreases significantly between these regions, and it is difficult to measure τ (see frame 3). The envelope of the jump is not smooth, as is clearly seen on the derivative signal for region 3 (frame 4) (the peak corresponding to the jump is followed by a noise burst). There is also a singularity on the falling side of the REE in the presence of the jump. The jump falls off much more rapidly than the REE (see the derivative signal on frame 3). In addition, a nonmotonic decrease of the REE is observed for sample 2 (frame 6).

The REE depends on the angle of rotation of the field H_0 in the plane of the sample. This dependence is roughly proportional to $\sin \phi$ (ϕ is the angle between H_0 and E) in the case of sample 1. In the region of the REE maximum, the jumps exist in a rather wide range of ϕ ($\sim 30°$). There are also very narrow (5 - 10°) regions that are symmetrical ($\pm \pi/3$) relative to $\phi = \pi/2$. Region 1, however, does not exist for these regions ($H_0 \sim 4.5$ kOe). At 78°K, all three values of ϕ ($\pi/2$ and $\pi/2$ $\pi/3$) occur at the maxima of the REE (the zeroes of the REE are in the same locations as at 4.2°K). It is possible that at $T = 4.2°K$, under conditions when weakly dampled magnetoplasma waves (MPW) exist, the REE is connected with holes whose Fermi surface is the isotropic in ϕ. The point is that the conductivity and the MPW velocity v_A (orientation of sample 1) are determined mainly by the holes [7]. At 78°K, when no MPW propagate, the REE has apparently also an electronic component, as is indeed manifest b -the presence of the three REE maxima when H_0 is rotated. The assumption that the REE jumps are connected somehow with the electrons agrees with the following

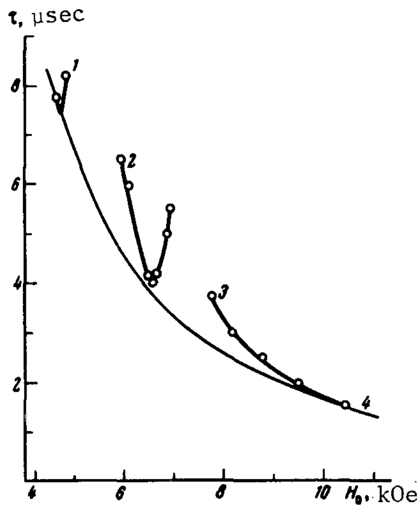

Fig. 2. Plot of $\tau(H_0)$ at $\phi = \pi/2$ (sample 1). 1, 2, 3 — three regions where the jump exists, 4 — H_0^{-2} dependence.

facts: The distance between the minima on the $\tau(H_0)$ curve (Fig. 2), namely $\Delta(H_0^{-1}) = 6\times10^{-5}$ Oe^{-1}, is close to the corresponding value of the period of the quantum oscillations (7.8×10^{-5} Oe^{-1}) [7] for light electrons. However, the very rapid change of $\Delta(H_0^{-1})$, from 7×10^{-5} Oe^{-1} to 3.5×10^{-5} Oe^{-1}, which occurs when H_0 is rotated 5 - 10°, still remains unexplained.

We investigated the dependence of the REE and of the jump on the microwave power in region 2 (Fig. 3). The value of the REE was measured before the jump ($t = 5$ μsec) and the value of the REE at the jump was measured at the end of the pulse ($t = 10$ μsec). At a power 200 W ($H \sim 13$ Oe, a sharp kink appears on the current-power curve. The kink is apparently even steeper, since τ depends also on the power (curve 3, Fig. 3), and nonstationary values of the jump are marked on the curve 2 not far from the threshold. The REE saturates at powers 3 - 4 times larger than P, probably because of heating of the carriers (or the lattice) during the time of the microwave pulse. This is proved by the increase of the MPW damping at $P \sim P_{thr}$ in comparison with the damping at $P \sim 0.05\ P_{thr}$ but at the same average power. The heating occurs in a time shorter than 2 μsec, since the REE vs power plot at $\tau_p = 2$ μsec (at the same value of H_0) has the same form as curve 1 (Fig. 3). Moreover, this characteristic does not change also at $\tau_p = 10$ μsec, but in a field H_0 insufficient for the development of the jump. The lattice heating, as shown by a simple estimate, is of the order of 0.5°K at $P = P_{thr}$ and $\tau_p = 5$ μsec.

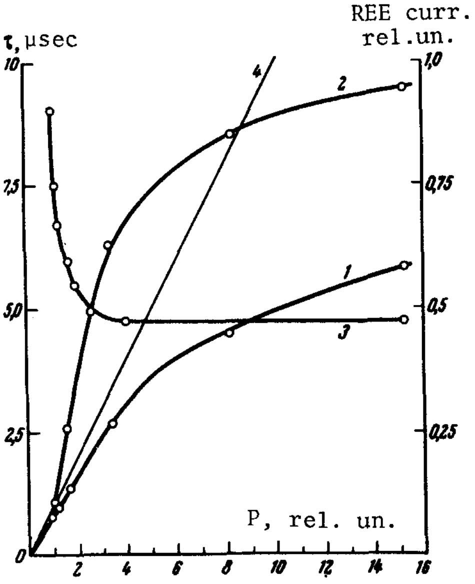

Fig. 3. Plots of and the REE (sample 1) against the power at $\phi = \pi/2$, $H_0 = 6590$ Oe. Curve 1 — REE, 2 — REE at the jump, 3 — time τ, 4 — linear plot of REE vs power obtained at low ($P < 20$ W). The corresponding points are not marked.

We point out in conclusion a certain analogy between the foregoing and the data of [8], where establishment of Cerenkov radiation of sound [9] by carrier drift in Bi in crossed fields E_0 and H_0 was investigated. It is easily shown for the two-band isotropic model of Bi that the Lorentz force not only leads to a constant REE along E (see, e.g., [2]) but also to a constant carrier drift into the interior of the semimetal. This drift is ω_H/ω times larger than the REE, and the threshold value of the drift velocity (sound velocity) is reached for the lightest carriers at $H \sim 10$ Oe and $H_0 \sim 6$ kOe. A kink on the current-voltage characteristic and a quadratic $\tau(H_0)$ dependence were observed in [8]. In our case, to the contrary, we have saturation of the REE and a nonmonotonic $\tau(H_0)$ dependence, although the minima of τ fit the H_0^{-2} curve fairly well (curve 4, Fig. 2). In addition, we investigated the variation of (H) at half the value of d (decreased by etching). The time remained practically unchanged. In [8], the value of τ increased somewhat with decreasing d.

1) In the radioelectric effect, a dc voltage (or current) proportional to the microwave poser appears in the metal.

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