The radioelectric effect in bismuth

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The transient radioelectric effect in bismuth at helium temperatures is studied in the UHF region. It is shown that in pulsed operation at powers $P \leq 1$ W the radioelectric effect has the same dependence on magnetic field (changes sign) as in continuous operation at low powers ($\sim 10^{-3}$ W). This radioelectric signal has a transient period less than 5×10^{-8} sec and with increasing power behaves nonlinearly (saturates). From estimates made of the thermal response time of the crystal it follows that for low powers ($\leqslant 1$ W) the radioelectric effect cannot be determined by the Nernst thermal e.m.f. For powers above 1 W, an inertial component of the radioelectric effect with a transient period of the order of 10^{-6} sec appears. This signal does not change sign with increasing magnetic field, and its transient period increases monotonically with increasing magnetic field. It is evident that this component of the radioelectric effect is due to thermal effects in the bismuth lattice. It is emphasized that the carrier energy-relaxation time in bismuth is quite measurable.

Experiments [1,2] on the radioelectric effect (REE) at ultrahigh frequencies in bismuth at helium temperatures have stimulated a number of articles which discuss the mechanisms on which this phenomenon is based. We will discuss briefly only those studies closest to experiment and having the purpose of explaining specific features of the REE. Kaganov and Peshkov [3] study the Hall mechanism of REE due to action of the magnetic field of a microwave on the current carriers in bismuth. Several authors [2,4,5] consider the possibility of heating of the carriers or lattice by the UHF field and the appearance of a thermal e.m.f. associated with this heating. Obviously, various heating mechanisms should be more inertial than the Hall mechanism. Therefore study of the establishment of the REE voltage can provide necessary information on the nature of the REE. For this reason we undertook the present study of the REE, using a pulsed technique. The latter permits increasing the microwave power without subjecting the sample to excessive heating. In addition, the pulsed mode of operation is interesting also in connection with observation of REE jumps. [6]

EXPERIMENT

In refs. 1 and 2 the REE was studied in the continuous mode with a UHF power not exceeding 10^{-3} W. The present work was carried out in the range of powers[1)] 1—100 W at a frequency of 9 GHz in two different pulsed modes of the microwave generator: with rectangular pulses of length $\tau_p = 1-10$ μsec with a rise time ~ 0.05 μsec, and with ringing pulses of duration 0.05 μsec. To avoid an average heating of the sample, the microwave pulse repetition frequency was of the order of 10 Hz. All measurements were carried out by means of a video amplifier (bandwidth 20 MHz, gain ~ 100) connected to the input of a S1-15 oscillograph. The smallest signals investigated had a height of about 0.5 mV, which corresponded to a microwave generator power $P \sim 1$ W. The sample in the form of a disk of diameter 1.8 cm and thickness d = 0.1, 0.2 cm served as the end wall of a TE_{101} rectangular copper resonator with a loaded Q of ~ 500, matched to a waveguide. The dimensions of the resonator were such ($1.7 \times 0.8 \times 4.5$ cm) that only a small part of the resonator loss was determined by the bismuth. Thus, in a field $H_0 \sim 700$ Oe about 2% of the power from the microwave generator is absorbed in the Bi crystal, and in a field of 6.5 kOe—20%.

The crystals of Bi ($C_3 \parallel N$ with a spread of $\sim 5°$) were grown from initial material Bi-0000 in a demountable quartz mold. The REE voltage was taken from two pairs of contacts made of copper foil of thickness 20 μ and welded to the unirradiated side of the Bi sample by means of a capacitor discharge with an energy ~ 0.1 J. One pair of contacts was located along the line I of the microwave current (the main contacts); the other pair was perpendicular to I (supplementary contacts). The direction of I coincided with the C_2 axis within 10°. The magnetic field H_0 was rotated relative to the microwave current I in the plane of the Bi. All of the dependences were taken for two positions of the magnetic field: for $H_0 \perp I$ the signal is maximal on the main electrodes and zero on the supplementary electrodes, and for $H_0 \parallel I$ the reverse is true.

1. Operation in Short-Pulse Mode at T = 1.45 K

At low powers ($P \sim 1$ W) the REE signal voltage completely follows the form of the microwave pulse. Hence it follows that the inertia of the REE is less than 5×10^{-8} sec. The dependence of the REE voltage on magnetic field is shown in Fig. 1. The oscillations of the REE signal correspond to magnetoplasma waves with a velocity $v \cdot H_0^{-1} = 2 \times 10^4$ cm/sec-Oe ($\Delta H_0^{-1} = 1.2 \times 10^5$ Oe^{-1} for d = 0.1 cm and $\Delta H_0^{-1} = 0.6 \times 10^5$ Oe^{-1} for d = 0.2 cm). On increase of the power ($P > 10$ W) the pattern shown in Fig. 1 is distorted. The negative REE values decrease sharply in comparison with the positive values, and the dependence on power is different for different values of H_0. This, the negative signal for $H_0 = 8.0$ kOe is rapidly saturated (curve 3, Fig. 2), while the positive signal (at the minimum, $H_0 = 5.6$ kOe) continues to rise monotonically (curve 1). The signal at the maximum ($H_0 = 7.5$ kOe) rises completely linearly (curve 2).

We note that for powers $P > 10$ W, after the REE pulse reproducing the envelope of the microwave generator, there appears a signal of duration of the order of microseconds.

2. Operation in Long-Pulse Regime at T = 1.45 K

Even at low powers ($P \sim 5$ W) the REE signal shows inertia. From oscillograms of the REE voltage (see for example Fig. 5 below) it is evident that the REE voltage pulse consists of two components: inertialess and inertial, with a characteristic time of establishment of the order 10^{-6} sec. The inertial component is positive for all values of H_0, i.e., it agrees in sign with the inertialess component for $H_0 < 6$ kOe. The time of establishment (τ) of the inertial signal depends on the magnetic field H_0. Figure 3 shows a substantial rise of τ for the REE signal from the main contacts (curve 1) and an insignificant drop in τ for the signal from the auxiliary contacts. In a sample of twice the thickness, the nature of the dependence remains the same, but the times are longer by 2—2.5 times.

The dependence of the REE on magnetic field for very low powers ($P \sim 1$ W) follows in its general features the behavior of the REE in the short-pulse regime. However, with increasing power ($P > 10$ W) the signal from the main contacts, oscillating as a result of excitation of magnetoplasma waves, already does not become negative. (Here we are discussing the established REE signal, which occurs in times of the order of several microseconds). Analysis of the oscillograms to separate the inertialess component shows that the latter behaves as before (in the short-pulse regime), i.e., it changes sign with increase of H_0. The inertial component, which varies monotonically, does not undergo sharp oscillations.

Let us trace how the REE signal changes as a function of the UHF power in the different magnetic-field regions. In Fig. 4, curve 1 represents the dependence of the stationary REE voltage at $t = \tau_p$ from the main contacts for $H_0 = 5.6$ kOe. Curve 2 corresponds to the inertialess part of the signal obtained as the result of analysis of the oscillograms. The difference between curves 1 and 2 gives the power dependence of the inertialess component (curve 3). The inertial component obtained in a similar manner from the auxiliary contacts (curve 6) turns out to be smaller, although the stationary signals are approximately the same. A completely different pattern is observed on the main contacts for $H_0 > 7$ kOe. In Fig. 5 (frames 1—3) we have shown REE oscillograms for $H_0 = 8.05$ kOe (the minimum of U) at various levels of microwave power. The appearance and development of the inertial component, which here ($H_0 > 7$ kOe) is always subtracted from the inertialess component, can easily be seen. It also follows from the oscillograms that the inertialess component decreases with time t (with increase of the microwave energy accumulated in the sample). This can be judged from the relative decrease in the vertical rise at the end of the microwave pulse, which has already disappeared in frame 3. (The

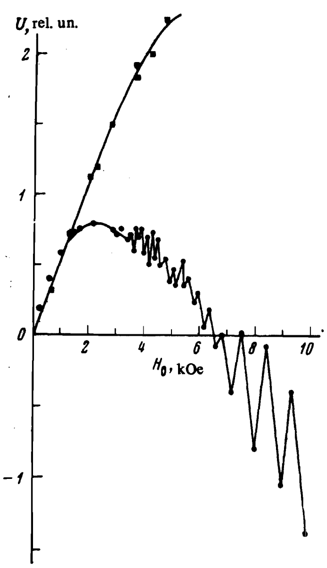

FIG. 1

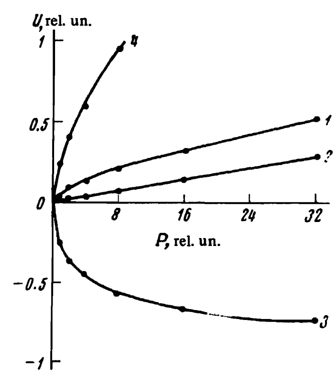

FIG. 2

FIG. 1. Dependence of REE voltage on magnetic field in sample with d = 0.1 cm. The circles are the signal for $I \perp H_0$, and the squares are for $I \parallel H_0$.

FIG. 2. Dependence of REE voltage on microwave power for different values of H_0 in the short-pulse regime (P = 1 for a microwave power of 20 W): curve 1) $H_0 = 5.6$ kOe; 2) $H_0 = 7.5$ kOe; 3) $H_0 = 8.0$ kOe; $I \perp H_0$. 4) $H_0 = 5.6$ kOe, $I \parallel H_0$.

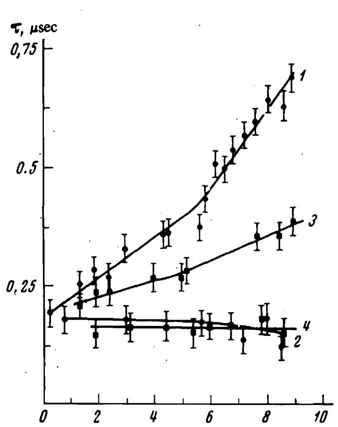

FIG. 3. Dependence of the establishment time τ for REE voltage on magnetic field for sample with d = 0.1 cm (P = 70 W). Curve 1) ($I \perp H_0$) and 2) ($I \parallel H_0$)—for T = 1.45 K. Curves 3) ($I \perp H_0$) and 4) ($I \parallel H_0$) —for T = 4.2 K.

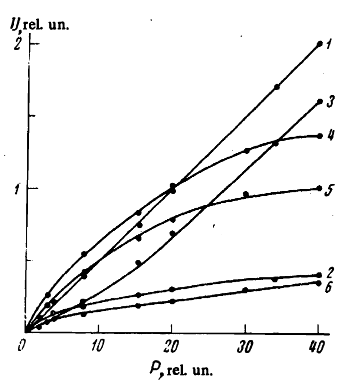

FIG. 4. Dependence of REE voltage on microwave power for d = 0.1 cm, $H_0 = 5.6$ kOe and $\tau_p = 6$ μsec. P = 1 for a microwave power of 6 W. The straight line 1 is the stationary signal for $I \perp H_0$, curve 2 is the inertialess component, curve 3 is the inertial component. Curves 4, 5, and 6 are the same but for $I \parallel H_0$.

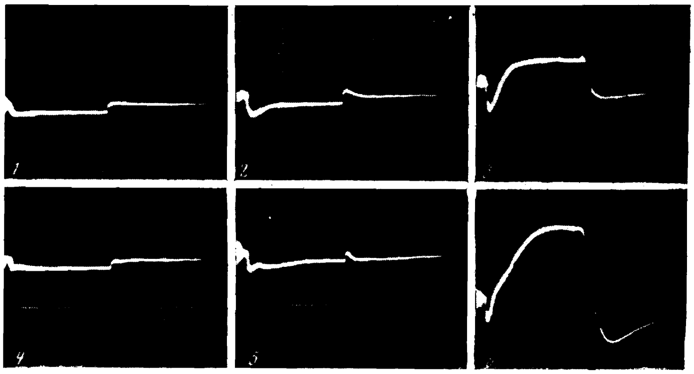

FIG. 5. Oscillograms of REE voltage for different levels of microwave power. Frames 1 (1.3 W), 2 (6W), and 3 (19 W) are for a sample with d = 0.1 cm at $H_0 = 8.05$ kOe. Frames 4 (5 W), 5 (20 W), and 6 (80 W) are for a sample with d = 0.2 cm at $H_0 = 9.45$ kOe. The abscissa represents time. A large division is 2 μsec. The ordinate shows the voltage, and a large division is 1 mV.

presence of this rise indicates that the inertial signal is added to a negative inertialess signal which is instantaneously turned off with the termination of the microwave pulse.)

Let us trace how the magnitude of the inertial component depends on the microwave power. In Fig. 6, curve 1 characterizes the variation of the stationary signal, which changes sign with increase of power. The negative peak, which shows distinct saturation (see frames 2 and 3 in Fig. 5), is shown in curve 2. The difference curve 3 corresponds to the inertial REE component.

The oscillograms for the thicker sample are somewhat different (Fig. 5, frames 4—6). As already pointed out, the time for establishment of the inertial signal is greater and, in addition, there is an additional break (see frame 5) beginning at $t = 0.8\ \mu$sec after the microwave generator is turned on.

In conclusion, we note that the negative peak in its rising portion does not have only an inertialess component, since its maximum occurs $0.25\ \mu$sec after the microwave generator is turned on (for the two samples with d = 0.1 and 0.2 cm).

3. Temperature Dependence of REE

At 4.2 K the dependence of the REE on magnetic field in the long-pulse regime is similar to $U(H_0)$ at 1.45 K but at a very high power where the negative value is much less than the positive values. The establishment time of the inertial component is somewhat smaller; the dependence $\tau(H_0)$ appears weaker (curves 3 and 4 in Fig. 3). The rise in the value of the REE with cooling in the range from 4.2 to 1.45 K is quite significant. Thus, the stationary signal for $H_0 = 1$ kOe increases with cooling by 7 db, while the negative inertialess signal at $H_0 = 9.8$ kOe increases by 10 db. For the same magnetic field the stationary signal changes sign on cooling, becoming negative at T = 1.45 K (the microwave power is low enough). For $H_0 \sim 5.6$ kOe the stationary signal is practically unchanged, although the signal from the auxiliary contacts increases by 10 db. Thus, it can be concluded from the above that the inertial part of the signal is practically unchanged in magnitude with cooling (in the range 4.2—1.45 K), while the inertialess part rises by about a factor of ten.

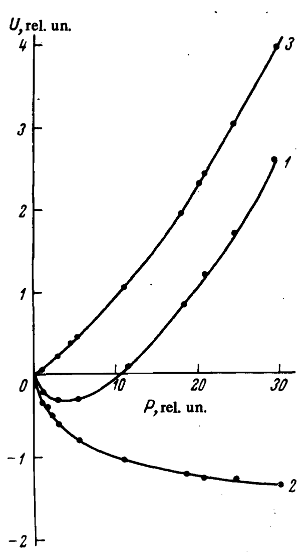

FIG. 6. Dependence of REE voltage on microwave power for $I \perp H_0$ for a sample with d = 0.1 cm; $H_0 = 8.05$ kOe, $\tau_p = 6\ \mu$sec. P = 1 for a microwave power of 5 W. Curve 1 is the stationary REE value, curve 2 is the peak value of the negative inertialess signal, and curve 3 is the difference in values of curves 1 and 2.

DISCUSSION OF RESULTS

1. Khaĭkin and Yakubovskiĭ [2] showed that for $I \perp H_0$ the REE voltage behaves as a function of the magnitude of H_0 as follows. Oscillating as the result of excitation of magnetoplasma waves in fields greater than 6 kOe, the value of U becomes negative, and the average value of the voltage passes through zero linearly. In the present work a similar behavior is observed for the inertialess component at powers up to tens of watts. This characteristic behavior of the REE has not received a sufficiently convincing explanation up to the present time. Below we will show that the Hall mechanism, in the simplest two-band isotropic model [3] of Bi, generally does not produce a change in sign of the REE voltage. Further, in spite of the fact that excess heating of the unirradiated surface of the sample in comparison with the irradiated surface, which is possible in sufficiently strong magnetic fields H_0, in principle gives a change in sign [4] of the REE, consideration of the real experimental conditions does not permit us to accept this explanation unconditionally.

In terms of ref. 3, the expression for the REE electric field in an open-circuited sample has the form

$$\bar{E}_x = -\frac{\varepsilon E_0^2}{(\varepsilon-1)c[4\pi n(m_1+m_2)]^{1/2}} \times\left[2\frac{\varepsilon+1}{\varepsilon-1}\frac{\operatorname{ch} z-1}{z}+\frac{4\sqrt{\varepsilon}}{\varepsilon-1}\frac{\operatorname{sh} z}{z}+\omega\tau\frac{1-\cos\varphi}{\varphi}\right] \times\left[\sin^2\frac{\varphi}{2}+\operatorname{sh}^2\left(\frac{z}{2}+\ln\frac{\sqrt{\varepsilon}+1}{\sqrt{\varepsilon}-1}\right)\right]^{-1}, \qquad (1)$$

where $\epsilon \equiv \epsilon' \gg \epsilon''$, $\varphi = 2k'd$, $z = 2''d = \varphi/2\omega\tau$. The remaining designations are the same as in ref. 3. Under the experimental conditions of ref. 2, $\omega\tau = 35$, $\varphi = 1350H_0^{-1}$, $\sqrt{\epsilon} = \varphi/2k_0d = 1.1\varphi$ (H_0 is measured in kOe).

It is evident from Eq. (1) that $\overline{E}_x$ cannot change sign with increase of H_0 (i.e., with decrease of z).[2)] Another situation exists with the mechanism described in ref. 4. Here the constant electric field in an open-circuited sample is proportional to the difference in temperatures on the irradiated and non-irradiated sides of the sample:

$$\bar{E}_x = \frac{\alpha_{xy}}{d}[T(0)-T(d)], \qquad (2)$$

where α_{xy} is the thermoelectric constant and T is the temperature of the lattice or the carriers. According to theory [7] and experiment [8] we have for the thermoelectric e.m.f. of the Bi lattice $\alpha_{xy} = -\alpha H_0$, $\alpha > 0$. Solving the stationary problem of heat conduction and taking into account the propagation of magnetoplasma waves, following ref. 4, we will write the expression for $\overline{E}_x$ in the form

$$\bar{E}_x = -\frac{2E_0^2\alpha_{xy}\,d\varepsilon}{(2\varkappa_{yy}+hd)(\varepsilon-1)\tau}\left[\frac{\varepsilon+1}{\varepsilon-1}\left(\frac{\operatorname{sh} z}{z}-2\frac{\operatorname{ch} z-1}{z^2}\right)+\frac{2\sqrt{\varepsilon}}{\varepsilon-1}\left(\frac{\operatorname{ch} z+1}{z}-2\frac{\operatorname{sh} z}{z^2}\right)+\frac{\sin\varphi}{\varphi}-4\frac{\sin^2(\varphi/2)}{\varphi^2}\right] \times\left[\sin^2\frac{\varphi}{2}+\operatorname{sh}^2\left(\frac{z}{2}+\ln\frac{\sqrt{\varepsilon}+1}{\sqrt{\varepsilon}-1}\right)\right]^{-1}, \qquad (3)$$

where $\mathscr{K}_{yy}$ is the thermal conductivity of Bi and H is the thermal conduction of the sample boundary. As in the derivation of Eq. (1), we have made the approximation $\epsilon' \gg \epsilon''$, and ϵ'' has been taken into account only in the arguments of the exponentials.

Equation (3) differs from the corresponding formula in the work of Kogan[4] in the presence of a resonance denominator, which it is important to take into account in discussing the average value $\overline{E}_x(H_0)$.

We will investigate the dependence of $\overline{E}_x$ on a magnetic field $H_0 \sim \varphi^{-1}$. It is easy to show by direct evaluation of the numerator of Eq. (3) that in the interval $0 < H_0 < 35$ kOe ($\infty > z > 0.6$) the REE signal does not change sign. Then it is easy to see that in the interval $0.1 < z < 6$ ($2\pi < \varphi < 14\pi$) Eq. (3) can be simplified (the error in the first square bracket does not exceed 2%):

$$\overline{E}_x = -\frac{2E_0^2\alpha_{xy}d}{(2\varkappa_{yy}+hd)\tau}\left[\frac{z^2}{12}+\frac{2k_0dz}{3\varphi}+\frac{\sin\varphi}{\varphi}-4\frac{\sin^2(\varphi/2)}{\varphi^2}\right] \times\left[\sin^2\frac{\varphi}{2}+\left(\frac{z}{2}+\frac{2}{\sqrt{\varepsilon}}\right)^2\right]^{-1} \quad (4)$$

(according to the experimental data of Khaĭkin and Yakubovskiĭ[2] $k_0dz/\varphi = 0.64 \times 10^{-2}$).

The condition for change of sign of $\overline{E}_x$ has the form

$$z^2/12+4.3\cdot10^{-3}\leqslant\varphi^{-1},\ z\leqslant0.55, \quad (5)$$

from which it follows that only for $H_0 \geq 35$ kOe is a change of sign of $\overline{E}_x$ possible. Furthermore, the maximum values of $\overline{E}_x$ (resonance in a plane-parallel plate for $\varphi = 2\pi N$, where N are integers) are always of the same sign, while the minimum values for $\varphi = 2\pi(N - 1/4)$ in the region of oscillations of $\overline{E}_x$ ($\varphi \geq 4\pi$) are always less in absolute value than the maximum values (the minimum of the microwave field in the plate occurs for $\varphi = (N + 1/2)2\pi$). Hence it follows that the average value $\overline{E}_x$ in the region of oscillations ($\varphi \geq 4\pi$) does not change sign.[3)]

2. In the present work we have established that for powers of the order of 10 W an inertial component ($\tau \leq 10^{-6}$ sec) appears in the REE, which does not change sign with increase of the magnetic field. An inertial signal of this type obviously cannot be explained by a single electron mechanism without participation of the lattice. We can assume that this part of the REE is the Nernst thermoelectric e.m.f. (2), which is determined by the unequal heating of the ends of the sample. We will estimate the time of establishment of this type of REE signal.

Without yet dwelling on the question of how the energy of the electron system (the microwave field acts directly on the electrons) transfers to the lattice, we will evaluate the characteristic time of establishment of a temperature gradient in a lattice on which is acting a distributed heat source instantaneously turned on and then constant in magnitude. Let the system be one dimensional (y) and let heat be exchanged only at the boundaries. For this purpose it is necessary to solve the nonstationary equation of heat conduction with a right-hand side dependent on y, with boundary conditions of the third type and with a zero initial condition. Introducing in the usual way the substitution $T(y, t) = T(y) + \overline{T}(y, t)$, we will reduce the problem formulated to two simpler problems. The solution $T(y)$ of the equation of heat conduction with a right-hand side dependent on y is found directly by integration (see for example ref. 4); the solution $\overline{T}(y, t)$ of the homogeneous equation of heat conduction with the initial condition $\overline{T}(y, 0) = -T(y)$ is given in the book by Carslaw and Jaeger.[9] As a result we will have an expression for $T(y, t)$ in the form of a rapidly converging series. Limiting ourselves to the first principal terms, we find that the time characterizing establishment of the average temperature of the sample is determined by $\tau_0^{-1} = 2HK/d$, and the establishment of the difference in temperatures at the ends by $\tau_1^{-1} = \pi^2K/d^2$ (here we have used the fact that the heat conduction of the Bi boundary is low: $Hd \ll 1$), where H and K are the thermal conductivity of Bi and of the boundary.

On the basis of data on the thermal conductivity of Bi,[10] the Bi boundary,[11] and liquid helium, we will estimate the time characterizing the lattice temperature of Bi ($C_3 \parallel \nabla T$):

$$T=2\text{ K},\quad \tau_0\approx50\,\mu\text{sec},\quad \tau_1\approx0.2\,\mu\text{sec}, \quad (6)$$

The value obtained for the time τ_1 is very close to the time of establishment of the inertial component, which was shown in Fig. 3. However, this fact is not worth reevaluating, since in thin samples of Bi ($d \ll 1$ cm) for sufficiently high thermal conductivity the effective mean free path of phonons is $l_{ph} \geq d$, and therefore the time of establishment of the lattice temperature is of the order $\tau_1' = d/s = 10^{-6}$ sec $> \tau_1$ (for d = 0.1 cm). It is not excluded that the increase in τ by only 2—2.5 times in a sample with d = 0.2 cm can be explained in just this way.

It is interesting to note that the oscillatory nature of the falloff of the REE inertial component occurring after termination of the action of the microwave pulse (Fig. 5) may be due to invalidity of the equation for heat conduction in description of the kinetics of heat in the bismuth lattice under the conditions of the experiment described.

3. Finally we will consider the mechanism of energy transfer from the charge carriers to the lattice. As we will show below, this mechanism turns out to be also rather inertial, and it alone is sufficient to explain the nature of the inertial component observed in the present work.

From the balance equations for the lattice and electron temperatures (see for example ref. 5) it follows that the time of transfer of the energy of the hot carriers to the lattice is determined by

$$\tau_1''=\tau_E C/n_0, \quad (7)$$

where τ_E is the energy-relaxation time of the carriers, C is the heat capacity of the lattice in units of k, and n_0 is the carrier concentration.

Green[12] obtained an expression for τ_E in the case of degenerate carriers:

$$\tau_E=\tau_p\frac{\pi^2k^2T(T+T_e)}{16ms^2E_F} \quad (8)$$

(k is the Boltzmann constant; m, T_e, and E_F are the mass, temperature, and Fermi energy of the carriers; T is the lattice temperature; and τ_p is the momentum relaxation time of the electrons). Using the expression[4)] for τ_p taken from ref. 13, for carriers with mass $0.2m_0$ (m_0 is the mass of the free electron) we obtain for T = 1.5 K

$$\tau_1''\approx0.25\cdot10^{-6}\left(1+\frac{T_e-T}{2T}\right)\text{ sec}, \quad (9)$$

which agrees with the time of establishment of the inertial component in a low magnetic field (Fig. 3). We recall that in bismuth the anisotropy of carrier mass is such that $1.3m_0 > m > 0.006m_0$.

The rate of energy transfer from the carriers to the lattice evaluated here contains also the dependence of τ_1'' on magnetic field (Fig. 3). For $I \parallel H_0$ and large H_0 a strong normal skin effect occurs for the microwave field, while the impedance for this polarization does not depend on the magnetic field. For $I \perp H_0$ in large fields, weakly damped magnetoplasma waves exist and the monotonic part of the energy flow into the metal increases with increasing H_0. In spite of this great difference in the distribution of the microwave field in the thickness of the metal, the heating of the electrons will be rather uniform in the two cases. This is due to the fact that the mean free path $l_E = v_F\sqrt{\tau_p\tau_E}$ of an electron with energy loss is of the order of the thickness of the sample and the relation between the temperature of the hot electrons and the heating microwave field is not local (the anomalous energy skin effect). Thus, for $I \perp H_0$ the electron temperature T_e and therefore also τ_1'' increase with increasing H_0.

4. As already pointed out, the dependence of the inertialess signal ($\tau < 5 \times 10^{-8}$ sec) on magnetic field has the same nature (Fig. 1) as the effect in ref. 2 (continuous operation, powers $P \sim 10^{-3}$ W). Then, proceeding from the ratio of the inertial and inertialess components of the REE determined[5)] from Fig. 4, we can conclude that at low powers $P < 10$ W) over the entire range of variation of the magnetic field (10 Oe $< H_0 <$ 10 kOe) a dominant role is played by the inertialess signal ($\tau < 5 \times 10^{-8}$ sec), and apparently it was studied in ref. 2.

The estimates made in paragraphs 2 and 3 of this section show that the inertialess signal cannot be due to the crystal lattice. Probably it is produced by the thermoelectric e.m.f. existing as the result of nonuniform heating of the carriers. In this case the observed saturation of the inertialess component of the REE (Fig. 2) can be naturally associated with the extraordinary increase of the electron temperature. In fact, the inertialess component depends very strongly on the temperature (see paragraph 3 of the experimental description and also ref. 2), and an elementary adiabatic estimate shows that for $P \sim 100$ W the electron system (at 2 K) is heated in 0.05 μsec to several degrees.

CONCLUSION

Using a pulsed technique for study of the REE, we have been able to distinguish two components: an inertialess component which is dominant at low microwave powers ($P \le 1$ W) and an inertial component arising at powers of the order of 10 W where the inertialess component undergoes saturation. The latter fact indicates that the inertialess signal is evidently associated with hot carriers whose temperature appreciably exceeds the lattice temperature.

At 1.5 K the inertial component has an establishment time $\tau \le 10^{-6}$ sec, which indicates the lattice origin of this signal. The study of the inertial component was carried out for the condition $\tau < \tau_p \ll \tau_0$, which assured the absence of an extraordinary heating of the bismuth lattice.

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1)The amplitude H of the magnetic field of the UHF wave in the metal in this case assumes values 0.6–6 Oe.

2)Because of an algebraic error, Eqs. (27), (34), and (37) of ref. 3 should not be considered. In addition, we do not assume that $z \ll 1$ and $\sqrt{\epsilon} \gg 1$ as in the conditions of ref. 2 for $H_0 \geqslant 6$ kOe and $z \leqslant 3.2$. The author is grateful to M. I. Kaganov for discussion of this part of the present section.

3)Kogan [4] also raises the question of the change of sign of the average value of the first square bracket in Eq. (3). An estimate shows that this occurs for $z \sim 0.22$, i.e., for $H_0 \sim 87$ kOe. However, the average value of this quantity does not correspond to the average value $\bar{E}_x$ as a result of the necessity for taking into account the resonance denominator.

4)Here we use τ_p due to phonons, since collisions with impurities (which determine the residual resistance) are elastic.

5)It follows from Fig. 4 that the inertialess signal on the auxiliary contacts is greater than the inertial signal (curve 5 is higher than curve 6). In the main contacts the inertialess signal (curve 2) exceeds the inertial signal (curve 3) for powers $P < 10$ W.

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