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LINEWIDTH OF CYCLOTRON RESONANCE IN BISMUTH

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An investigation of cyclotron resonance (CR) in metals makes it possible to determine the relaxation time of the carriers from the width of the resonance line. We have investigated experimentally the CR in bismuth in the frequency range f = 10 - 76 GHz, and observed a dependence of τ on f.

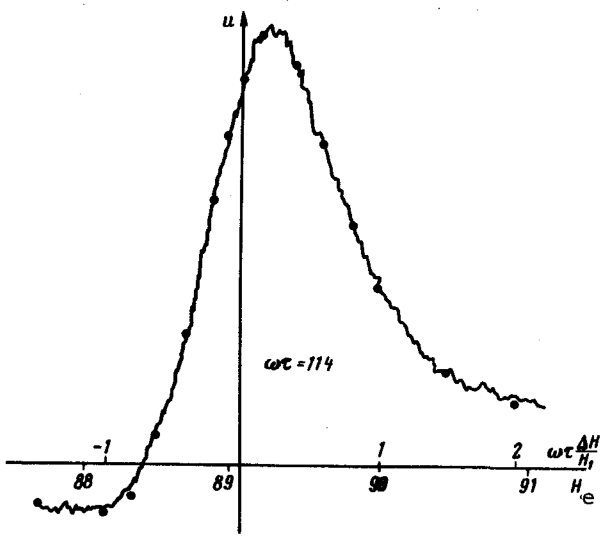

Fig. 1. Line of cyclotron resonance of first order in bismuth. H parallel to C_2, f = 26.4 GHz, T = 0.35°K. Solid line - experimental; points - calculation by formula (3).

The sample was single-crystal Bi whose normal was parallel to the trigonal axis C_3. It was grown from the melt in a dismountable quartz mold [2]. The sample served as the wall of a resonator. A strip resonator [2] was used at 10.22, 18.74, 26.4, and 37.1 GHz, and a cavity resonator with circular currents was used at 76.1 GHz. We measured the ac component of the signal power passing through the resonator and produced when the magnetic field is modulated at 12 Hz. The reflections from the elements of the microwave channel of approximate length $\sim 10\lambda$ made the system sensitive not only to changes of the resonator Q ($Q \simeq 10^3$), but also to changes of its natural frequency. The resultant signal was

$$U \sim a\,\partial X/\partial H + b\,\partial \chi/\partial H \cdot \quad (1)$$

The magnetic field H was produced by a system of Helmholtz coils. The field inside the sample was homogeneous within 0.1%. The earth's magnetic field was compensated for with three pairs of coils, accurate to $\sim$0.01 Oe.

We measured the relaxation time of the electrons of minimal mass ($m^* = 0.0094m_0$) with $\vec{H}$ parallel to the binary axis C_2. If the angle between the magnetic field and the high-frequency current $\vec{J}$ was less than 30°, then the observed CR was due only to the electrons belonging to one ellipsoid of the Fermi surface, and small orientation errors did not change the CR linewidth. Measurements at 18.74 GHz have shown that if the angle between $\vec{H}$ and C_2 is <10', then the angle between $\vec{H}$ and $\vec{J}$ has no effect on the position, form, and width of the CR. The CR signal did not depend on the working section of the sample situated under the strip (measuring 6.7 × 2 mm) or on an inclination of ±30' of the magnetic field relative to the plane of the sample. Nor was the CR linewidth affected by repeated cooling and heating of the sample to room temperature.

A sample plot of the CR line is shown in Fig. 1. $\omega\tau$ was determined from the following formula [1]:

$$Z = (R_0 + iX_0)\left(1 + \frac{a}{1 - i\mu}\right), \tag{2}$$

where R_0 and X_0 describe the surface impedance off resonance, $\alpha << 1$, and $\mu = \omega\tau\Delta H/H_n$. In the derivation of (2) it was assumed that the mass depends little on the momentum p_z, and the changes of R and X at resonance are small. They did not exceed ∿10% of the total surface impedance in our experiments.

For the line shape (1) we obtain

$$U \backsim A\frac{\mu}{(1+\mu^2)^2} + B\frac{1-\mu^2}{(1+\mu^2)^2} \quad . \tag{3}$$

In the case of the anomalous skin effect we have for the plot of $\partial R/\partial H$ the value $A/B = 2/\sqrt{3}$ [1]. However, taking into account (1) and the fact that the skin effect ceases to be anomalous (since we have for holes $V_F/\omega < \delta$ at ∿50 GHz) and the ratio of R_0 to X_0 changes [3], it is necessary to choose A/B such that expression (3) describes the observed line shape. For example, for the plot of Fig. 1 it was assumed that A/B = 1.4. The obtained value of $\omega\tau$ is not very sensitive to the value of this ratio: when the latter is changed by a factor of two (and then the calculated line shape differs appreciably from the observed one), $\omega\tau$ changes by ∿5%.

In the experiments made at 10.22 and 18.74 GHz, narrow resonant peaks (from the width of which $\omega\tau$ was determined) were observed against the background of oscillations of smaller amplitude (by a factor 3 - 5) and larger width (by 3 - 5 times). The nature of these oscillations is not clear, and they may be connected with cyclotron waves [4]. At higher frequencies they are not observed. In the reduction of the plots it was assumed that two lines of different amplitudes and widths are superimposed on each other, and the ratio of these quantities was chosen such as to agree with the observed picture. If this circumstance is not taken into account, then the obtained value of $\omega\tau$ is too low (by ∿30% and ∿10% at 10.22 and 18.74 GHz, respectively).

The linewidth at each frequency was measured for different orders of the CR (n = 1 - 4); the value of $\omega\tau$ within the limits of the measurement errors was independent of n.

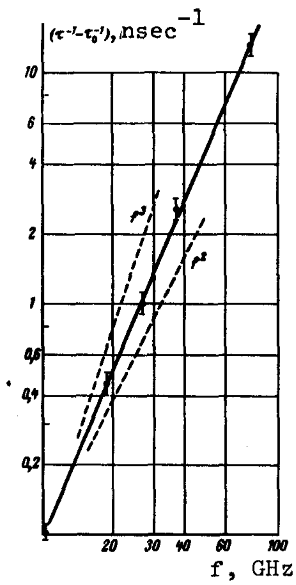

Fig. 2. Frequency dependence of $\tau^{-1} - \tau_0^{-1}$. The point corresponding to f = 76.1 GHz was obtained at T = 1.5°K, and the remaining points at T = 0.35°K. The error bars at the points represent the measurement errors.

The reciprocal relaxation time can be represented in the form $\tau^{-1} = \tau_0^{-1} + \tau^{-1}(f,T)$, where $\tau_0 = 2 \pm 0.2$ nsec is the residual relaxation time, determined by the impurities and by the crystal defects. According to Fig. 2, $\tau^{-1}(f, T = 0.35°K) = (f, \text{GHz}/26.4)^{2.5\pm0.2}\text{nsec}^{-1}$.

The observed frequency dependence of τ is apparently connected with the electron-electron interaction; the attenuation of the excitations is of the order of $(\hbar\omega)^2/E_F$ [6]. Substituting $E_F = 27.6$ meV [7] and $f \simeq 5 \times 10^{10}$ Hz, we obtain for the relative attenuation of the quasiparticles $\hbar\omega/E_F \simeq 10^{-2}$, corresponding to an experimental value $\omega\tau \simeq 10^2$. The fact that the power of ω is 2.5 and not 2

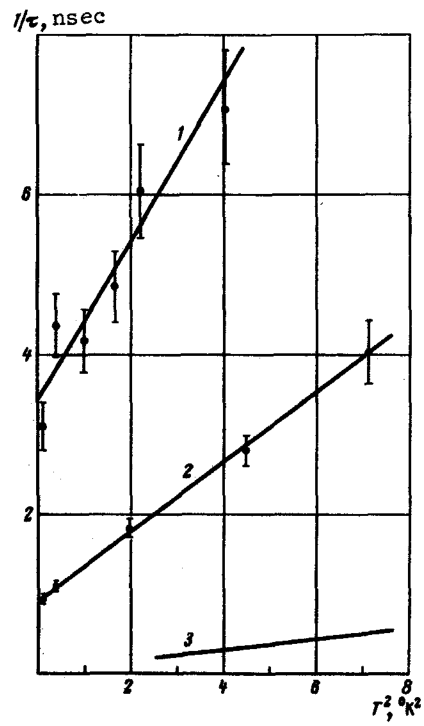

Fig. 3. Plot of $\tau^{-1}(T^2)$: 1 - f = 37.1 GHz, 2 - f = 18.74 GHz, 3 - $\tau^{-1}(T^2) - \tau_0^{-1}$ plotted from the data of [5], f ∿ 10 MHz.

is possibly connected with the electron-phonon interation, which leads to an excitation damping $\sim(\hbar\omega)^3/\omega_D^2$ [6].

The temperature dependence $\sim T^2$ is to be expected for the electron-electron interaction. However, the frequency dependence of the factor preceding T^2 remains so far unexplained.

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PRODUCTION OF MULTIPLY-CHARGED IONS BY INTERACTION BETWEEN A POWERFUL LASER PULSE AND A SOLID

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We have investigated the high-temperature plasma produced when laser radiation acts on a substance, at a maximum power W_{max} ∿ 2 GW.

The radiation block consisted of a 10 × 130 mm neodymium glass (laser) and two amplifiers with 30 × 306 (with Brewster angle) and 30 × 260 rods.

The radiation flux density, using a lens with f = 5 cm, was $\sim 10^{13}$ W/cm². The analyzing instrument was a time-of-flight mass spectrometer with superimposed E and H fields [1].

The investigated targets were made of Co^{27}_{59}, $Ag^{47}_{107-109}$, Ta^{73}_{181}, W^{74}_{184}, Bi^{83}_{209}. The maximum charges of the ions of these elements were Ag^{+16}, Ta^{+20}, W^{+19}, and Bi^{+19}.

A charge multiplicity up to 25 was obtained with the Co^{27}_{59} target. Figure 1 shows the experimental oscillograms of the ion pulses of Co^{27}_{59}. The ions with large charges were identified by means of the left end point of the oscillogram