Ne levels	Distance from $5s'[\frac{1}{2}]^{0}_{1}$		S^{e}_{3}/W^{R}_{3}		$\langle \sigma^{e}_{23} v_e \rangle$
	cm^{-1}	eV	i = 10 mA	i = 75 mA	cm^3/sec
4d'	1150	0.14	0.084	0.64	$\gg 6 \times 10^{-7}$
5d'	3630	0.45	0.13	1.0	$\gg 1.5 \times 10^{-7}$

$T_e \approx 7$ eV; $j \approx 2.5$ A/cm^2 and $n_e = 3.25 \times 10^{12}$ cm^{-3} when i = 75 mA.

level $5s'[\frac{1}{2}]^{0}_{1}$.

The described experiments show that even a relatively simple model with a linear dependence $y = f(1/n_e)$ is valid in some cases. These cases can be used for a direct determination of the effective cross sections of individual electronic processes. By making the model more complicated we can extend the range of applicability of the method.

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OBSERVATION OF QUANTUM SIZE EFFECTS IN THIN BISMUTH FILMS

Yu. F. Ogrin, V. N. Lutskii, and M. I. Elinson
Radio Engineering and Electronics Institute, USSR Academy of Sciences
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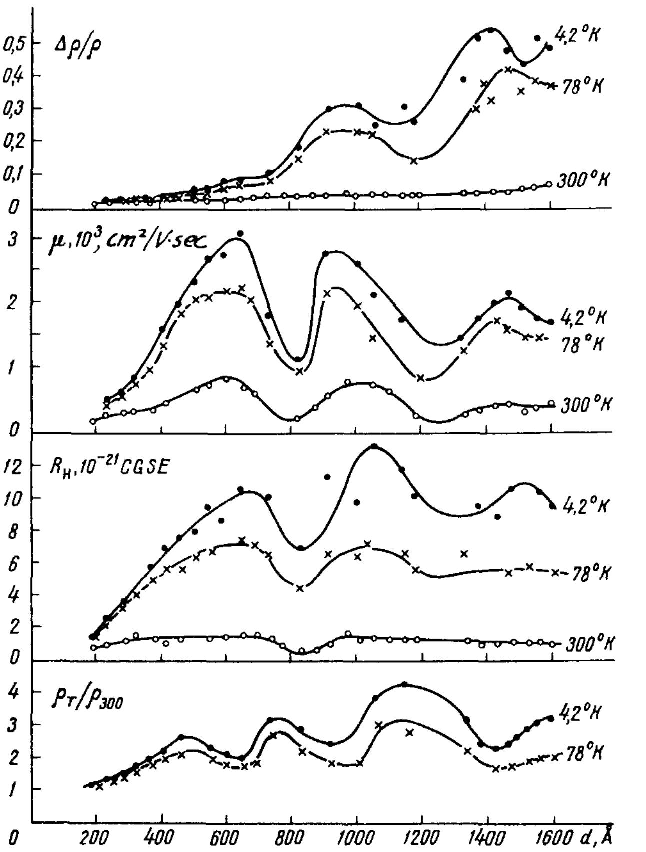
It is well known [1] that quantum effects should be manifest in the behavior of the carriers in semiconductor and metal films whose thickness (d) is comparable with the effective wavelength (λ) of the carriers. In particular, the kinetic and galvanomagnetic coefficients should oscillate when the film thickness is changed. These oscillations are analogous to the oscillations of the same quantities in a quantizing magnetic field. The effects indicated are particularly strongly pronounced at low temperatures.

To observe these quantum size effects it is necessary, besides satisfying the condition $\lambda/d \geq 1$, that the mean free path of the carriers (ℓ) be larger than the film thickness. It is natural to choose for the investigations a material with specular scattering of the carriers from the film boundaries.

From among the substances investigated to date, this requirement is apparently best satisfied by bismuth, for which $l \sim 1$ mm at 4.2°K [2] and the reflection from the sample boundaries is specular [2].

It is known [3] that the crystallites in thin Bi films obtained by vacuum sputtering on hot mica are oriented with the trigonal axis normal to the surface. The effective mass component (m_z^*) corresponding to this direction has a value $\sim 0.01 m_0$, and the value of the Fermi energy (ϵ_F) for Bi is 0.02 eV [4], so that the condition $\lambda/d \geq 1$ can be satisfied for reasonable values of d. It must also be noted that bismuth is a semimetal with small band overlap, and that one of the manifestations of quantum size effects should be its transformation into a dielectric (low temperature) as the thickness is reduced, and this should affect the kinetic, galvanomagnetic, and optical phenomena [5].

We have investigated the thickness dependence of the resistivity (ρ), the Hall constant (R_H), and the magnetoresistance ($\Delta\rho/\rho$) of Bi films at 300, 78, and 4.2°K (magnetic field perpendicular to the plane of the film). The films were prepared by sputtering pure (99.9999%) Bi in 10^{-6} mm Hg vacuum on mica heated to 70 - 80°C at a sputtering rate ~50 Å/min. To reduce the scattering in the values of the measured quantities, caused by difference between substrates, 12 samples of different thickness were sputtered on a single substrate. The thickness of the thickest sample was measured with an ordinary interference microscope, and the thicknesses of the other were determined from the sputtering time (the sputtering rate was assumed constant).



Electron-diffraction investigations have shown that the film structure had a texture in which the disorientation of the crystallites did not exceed 10 - 15°.

The measurements of ρ, $\Delta\rho/\rho$, and the Hall emf were made by a null method. Magnetic field magnitude during measurements was 8 kOe.

The thickness dependences of ρ_T/ρ_{300}, $\Delta\rho/\rho$, R_H, and the Hall mobility $\mu_x = R_H/\rho$ are plotted in the figure. A characteristic feature of these curves is the presence of oscillations of all the measured quantities as functions of the film thickness. The distance between neighboring maxima (or minima) is $\Delta d \simeq 400 - 500$ Å. The amplitude of the oscillations increases with decreasing temperature. The $R_H(d)$ and $\Delta\rho/\rho(d)$ plots are characterized also by a monotonic decrease of these quantities as $d \to 0$ (for $d < 600$ Å). We note that ρ increases rapidly with decreasing thickness when $d < 400$ Å.

Assuming the obtained oscillations to be manifestations of quantum size effects we can, using the experimentally measured period of the oscillations, estimate the effective mass of the carriers by means of the formula

$$\Delta d = \pi\hbar\,[2m_z^* \epsilon_F]^{-1/2}.$$

It is assumed that m_z^* does not depend on d, and that the Fermi energy (ϵ_F) of the bulk sample is equal to 0.02 eV. Substituting in this expression $\Delta d = 400$ Å we obtain $m_z^* = 0.01m_0$, in agreement with the known [4] value of the effective mass component corresponding to the trigonal axis. The rapid growth of ρ with decreasing d in the region $d < 400$ Å can be interpreted as a transition of the semimetal into a dielectric. Such an interpretation, however, calls for further research, for in this thickness range a similar effect is produced, for example, by breaks in the films.

Taking all the foregoing into consideration, we can assume with high degree of probability that the effects obtained are quantum size effects.

Nonetheless, this communication must be regarded as preliminary. To confirm the foregoing hypothesis we are presently carrying out investigations at greater film thicknesses, when the condition $\lambda/d \geq 1$ is not satisfied. In addition, the necessary control investigations of the structure of the film are now under way for a wide range of thickness.

It is also of interest to measure the dependence of R_H and of $\Delta\rho/\rho$ on the orientation and magnitude of the magnetic field, and also to carry out measurements that make it possible to observe distinctly the transition, with decreasing d, of a semimetallic film into a dielectric.

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