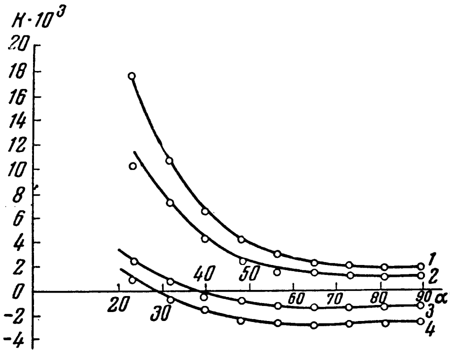
lier[1] was used with the following modifications: the target, which was the internal electrode of a spherical condenser, was a circular plate fastened to a hemisphere 28 mm in diameter, inside of which there was a tungsten helix for heating the target. The entire spherical condenser could be rotated about an axis in the plane of the target. As in the earlier work, the spherical condenser was located in a magnetic field directed along the axis of rotation of the target. The magnetic field required for suppression of electron emission was less than 100 oersted. A retarding potential of 400 volts was applied to the target to suppress the emission of slow secondary positive ions. All experiments were carried out in a vacuum of 2×10^{-6} mm Hg.

The relation obtained between the coefficient of secondary negative ion emission and the angle of entry of the beam are shown in the figure. As is apparent from the figure, in copper and E Ia–1 stainless steel this coefficient is positive over the entire entry-angle region which was studied. In aluminum and beryllium targets the secondary ion emission coefficient is negative at large entry angles; at entry angles below 30 — 40° it passes through zero and becomes positive.



The secondary ion emission coefficient as a function of entry angle of the primary proton beam in a plane target. 1 – Cu, 2 – stainless steel, 3 – Al, 4 – Be.

Preheating the targets at 900° C for 20 minutes results in a reduction of K^- in the beryllium targets and an increase in K^+ in the copper targets.

The present results can be understood if one keeps in mind the fact that the secondary-ion emission is composed of true secondary negative ions and of protons of the primary beam, scattered at angles larger than 90° by the Coulomb field of the target nuclei. The observed sign of the secondary-emission coefficient depends on the relative strengths of these two components.

The results obtained indicate that at proton energies of 50 kev in copper and stainless steel targets the number of scattered protons is larger than the number of secondary negative ions at all entry angles. In aluminum and beryllium targets the number of secondary negative ions exceeds the number of scattered protons at entry angles below 30 — 40°.

Attempts to compute the current of single positive scattered ions indicate that the calculation errors are as large as the experimental errors; hence it is impossible to determine accurately the negative-ion coefficient from the difference of currents when the present method is employed.

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[1] I. M. Mitropan and V. S. Gumeniuk, J. Exptl. Theoret. Phys. (U.S.S.R.) 32, 214 (1957), Soviet Phys. JETP 5, 157 (1957).

[2] J. S. Allen, Phys. Rev. 55, 336 (1939).

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CYCLOTRON RESONANCE IN LEAD AT 8,900 Mcs

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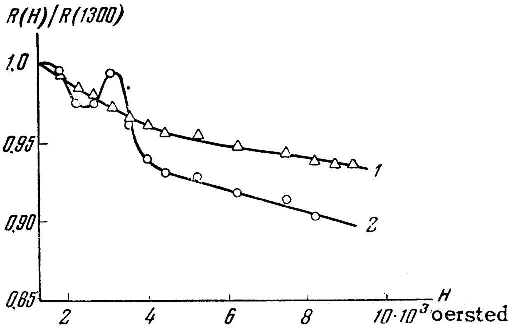
CYCLOTRON resonance effects in metals, predicted theoretically by Azbel' and Kaner,[1] have been recently observed experimentally in tin[2,3] and bismuth.[4]

In the present note we present a brief report concerning the results of experiments on cyclotron resonance in lead at 8,900 Mcs.

The choice of lead as a test material is occasioned by the following considerations. It follows from the theory of cyclotron resonance that the amplitude of the oscillations of surface resistance of the metal in the resonance region at a given frequency of the alternating electromagnetic field depends in an important way on the electron relaxation time in the metal t_0, increasing as t_0 increases. In contrast with the materials investigated earlier, such as copper and tin,[2,3] for which the dc resistance changes slowly in the helium-temperature region, lead has the feature that its conductivity in the helium temperature region increases significantly as the temperature is reduced,[5] indicating an increase in the electron relaxation time t_0. Thus, the change due to resonant effects, observed in the same sample of tin as the temperature was reduced from 4.2° K to 2° K,[3] should have a larger effect in lead, by virtue of the observations given above.

The sample was a lead single-crystal wire approximately 12 mm in length and approximately 0.8 mm in diameter extracted in a quartz capillary from lead obtained from the Kalbaum company;* the sample was placed along the axis of a coaxial copper resonator. The measurement of the surface resistance of the sample was carried out by the same methods used in studying cyclotron resonance in tin.[3]

The results of the measurements of R(H)/R(1300) [R(H) is the surface resistance in a fixed field H > 1300 oersted†] in lead at a frequency of 8,900 Mcs and temperatures of 4.2° K (Curve 1) and 2° K (Curve 2) are shown in the figure. The effect of electron relaxation time is obvious from the figure. At 4.2° a monotonic decrease of resistance is noted with increasing field; at a temperature of 2° K and H ≈ 2400 oersted there is rather deep resonance minimum followed by a maximum; then the surface resistance falls off sharply in accordance with the theoretical predictions. An estimate of the effective mass m^* of the conduction electrons in lead, carried out under the assumption that the resonance minimum at H = 2400 oersted corresponds to the condition $\nu = eH/2\pi m^*c$, yields the value $m^* = 0.8\ m_0$.



The fact that the obtained effective conduction-electron mass does not differ significantly from the free-electron mass indicates that just as in tin,[3] the electrons at the bottom of the band are responsible for the cyclotron resonance in lead.[6]

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[1] M. Ia. Azbel' and E. A. Kaner, J. Exptl. Theoret. Phys. (U.S.S.R.) **30**, 811 (1956), Soviet Phys. JETP **3**, 722 (1956).

[2] E. Fawcett, Phys. Rev. **103**, 1582 (1956).

[3] P. A. Bezuglyi and A. A. Galkin, J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 1076 (1957), Soviet Phys. JETP **6**, 831 (1958).

[4] I. E. Aubrey and R. G. Chambers, Physics and Chemistry of Solids (1957).

[5] E. S. Borovik, J. Exptl. Theoret. Phys. (U.S.S.R.) **27**, 355 (1954).

[6] E. S. Borovik, Doctoral Dissertation, Physico-Technical Institute, Academy of Sciences, Ukrainian S.S.R. (1954).

*The same samples of lead were investigated by Borovik.[5]

†In view of the fact that lead is a superconductor with $T_c = 7.2°$, the impedance in the field does not refer to the value of R at H = 0, but to its value at 1300 oersted, when the sample is in the normal state

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INVESTIGATION OF THE SURFACE RESISTANCE OF TIN IN WEAK MAGNETIC FIELDS

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IN work on cyclotron resonance[1] it has been shown that in weak fields parallel to the surface of the metal the surface resistance is a very weak function of the field. On the other hand, experiments carried out by Fawcett[2] on cyclotron resonance in tin and copper have shown that in weak fields there is a considerable dependence of surface resistance on field; dR(H)/dH is considerably different from zero as H → 0. The same conclusion may be drawn from our earlier work.[3]

In this connection we have investigated the surface resistance of tin in fields up to 100 oersted, using the method escribed earlier.[3] The results of these experiments, carried out with the tin sample used earlier[3] at a frequency of 9,300 Mcs and a temperature of 4.2° K are shown in the figure. These results indicate that, in accordance with the theoretical predictions, the real part of the resistance of the metal is virtually independent of