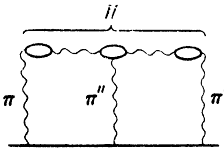

FIG. 2

To estimate the contribution to the moment from the three-pion state we use the relation of the magnetic moments to the corresponding mechanical moments and find that the magnetic moment of the three-pion state $\mathfrak{M}_{3\pi} \leq 0.1\,\mathfrak{M}_{2\pi}$, where $\mathfrak{M}_{2\pi}$ is the magnetic moment of the two-pion state. This also corresponds to previous results.[1,2]

In conclusion, I want to express my profound thanks to Academician N. N. Bogolyubov for valuable remarks and to Prof. L. I. Schiff for a productive discussion. I am grateful to A. M. Korolev, A. F. Lubchenko, and Yu. M. Malyuta for comments on various points of the work.

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*The mass of the "polarized" Π-pion $m \sim M$ (M is the nucleon mass), i.e., $m > \mu$ ($\mu$ is the mass of the "ordinary" pion π). The dimensions of the Π-pion $\sim \hbar/Mc$.[1]

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[1] R. Jastrow, Phys. Rev. **81**, 165 (1951). D. I. Blokhintsev, JETP **29**, 33 (1955), Soviet Phys. JETP **2**, 23 (1956). D. I. Blokhintsev, CERN Symposium **2**, 155 (1956). Blokhintsev, Barashenkov, and Barbashov, preprint P-317, Joint Inst. Nuc. Res., Dubna (1959).

[2] J. Bernstein and M. L. Goldberger, Revs. Modern Phys. **30**, 465 (1958).

[3] Hofstadter, Bumiller, and Yearian, Revs. Modern Phys. **30**, 482 (1958).

[4] H. Bethe and P. Morrison, Elementary Nuclear Theory, Russian Translation, IIL (1958).

[5] G. Chew, VIII Rochester conference on high-energy physics (1958).

[6] B. B. Dotsenko, Dokl. Akad. Nauk SSSR **119**, 466 (1958), Soviet Phys.-Doklady **3**, 307 (1958).

[7] A. Sommerfeld, Atombau und Spektrallinien, Russian translation V. 1, p. 85; V. 2, p. 83; Gostekhizdat (1956). [Braunschweig, 1939].

[8] P. Gombas, Das Mehrteilchen Problem der Wellenmechanik, Russian translation, IIL (1952) [Birkhausen, Basel, 1950].

Translated by W. Ramsay
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# *CYCLOTRON RESONANCE IN INDIUM AT 9300 Mcs*

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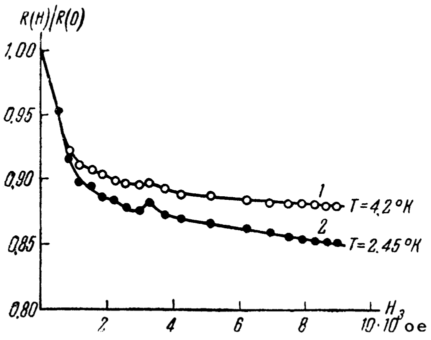
THE appearance of cyclotron resonance in metals, which was predicted theoretically by Azbel' and Kaner,[1,2] has so far been found in three metals: tin,[3-5] bismuth,[6-7] and lead.[8] In this note we present briefly the results of our experiments on cyclotron resonance in indium at 9300 Mcs.

The specimen was a ~ 12 mm long wire of diameter ~ 0.8 mm consisting of large crystals formed in a quartz capillary. At 4.2° K $\omega t = 30$ ($\omega$ is the circular frequency of the electromagnetic field, and t the electron relaxation time; the value of t was derived from the residual resistance.).

The surface resistance of the specimen was measured by the method previously described,[4] which is based on the determination of the change in tuning of a coaxial resonator, containing a cylindrical metal specimen, produced by applying an external magnetic field..

The results of measurements of the ratio R(H)/R(0) [R(H) is the surface resistance in a magnetic field, R(0) the resistance in the absence of a field] at 4.2 and 2.45°K are shown in the figure. The effective mass of the carriers responsible for the resonance can be calculated from the value of the field at which R(H)/R(0) is a minimum. From the theory we have, at the minimum, $\omega = eH/m^*c$, from which we obtain $m^* = 0.8 - 0.9\ m_0$, where $m_0$ is the free electron mass. This value of the effective mass shows that the main groups of electrons are responsible for the cyclotron resonance observed in indium.



Comparison of the curves for 4.2 and 2.45° K shows a sharpening of the resonance at lower temperatures. Such a sharpening was found earlier in lead[8] and is related to a noticeable increase in the relaxation time t. The dc resistance of the indium specimen does, indeed, decrease several fold as the temperature is reduced from 4.2 to 2.5° K.

Measurement of the field dependence of surface resistance of zinc and aluminium at liquid helium temperatures showed that at 9300 Mcs there is a slow decrease with increasing magnetic field. The absence of resonance effects in zinc and aluminum is apparently related to the breakdown of the conditions under which cyclotron resonance is observable ($\omega t \gg 1$).

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[1] M. Ya. Azbel' and É. A. Kaner, JETP **30**, 811 (1956), Soviet Phys. JETP **3**, 771 (1956); JETP **32**, 896 (1957), Soviet Phys. JETP **5**, 730 (1957).

[2] É. A. Kaner and M. Ya. Azbel', JETP **33**, 1461 (1957), Soviet Phys. JETP **6**, 1126 (1958).

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

[4] P. A. Bezuglyĭ,and A. A. Galkin, JETP **33**, 1076 (1957), Soviet Phys. JETP **6**, 831 (1958).

[5] Kip, Langenberg, Rosenblum, and Wagoner, Phys. Rev. **108**, 494 (1957).

[6] R. N. Dexter and B. Lax, Phys. Rev. **100**, 1216 (1956).

[7] J. E. Aubrey and R. G. Chambers, J. Phys. Chem. Solids **3**, 128 (1957).

[8] P. A. Bezuglyĭ and A. A. Galkin, JETP **34**, 236 (1958), Soviet Phys. JETP **7**, 163 (1958).

Translated by R. Berman
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# *ENERGY OF THE ELECTRON-PHOTON COMPONENT OF EXTENSIVE AIR SHOWERS*

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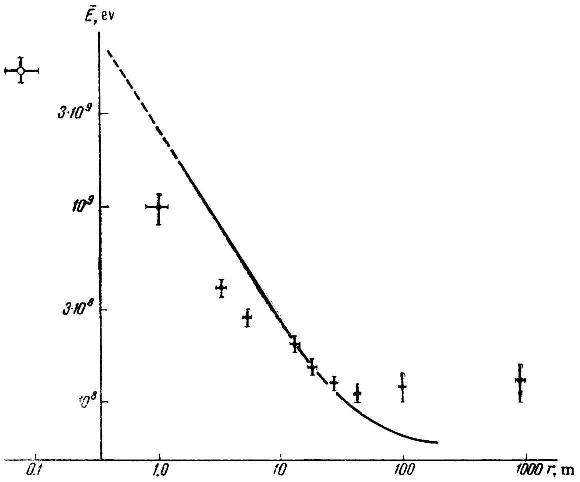
IN a previous article[1] we reported the results of measurements of the energy of the electron-photon component in the central region of extensive air showers (EAS). In the present investigation, measurements of the energy carried by the electron-photon component at lateral distances from 0.1 to 1000 m were made at sea level using the array for the comprehensive study of EAS. Practically the whole energy of the electron-photon component was thus measured directly, since the above-mentioned distance range contains about 90% of the total number of shower particles. The total energy of the electron-photon component is, on the average, proportional to the total number N of particles in the shower. The value of the energy of the electron-photon component is equal to $E_{e-p} = (2.7 \pm 0.3)\beta N$, where $\beta$ is the critical energy for air. The energy flux distribution in the central region of EAS is given in reference 1. At distances $100\,\mathrm{m} \le r \le 1000\,\mathrm{m}$, the distribution function of the energy flux can be represented in the form $\rho_E(r) \sim r^{-(2.6\pm0.2)}$.

Data on the mean energy of the particles of the electron-photon component have been obtained. The value of the mean energy per electron at various distances from the shower axis is given in Fig. 1.*



In the central region of the showers, for $0.1\,\mathrm{m} \le r \le 30\,\mathrm{m}$, the mean energy can be described by the function $\bar{E} = 10^9 r^{-(0.6\pm0.1)}$ ev, where r is in meters. At distances of 100 — 1000 m, the mean energy is constant and equal to $\bar{E} = (1.2 \pm 0.15) \times 10^8$ ev. A comparison with the theoretical curve obtained on the basis of the cascade theory for s = 1 by Kamata and Nishimura[3] (the curve is shown in the figure) reveals a considerable discrepancy between experimental and theoretical results. The observed increase in the mean energy with decreasing distance from the shower axis is smaller than the calculated one. At the same time, the measured mean energy at the shower periphery is higher than the theoretical value. A less-pronounced variation of the mean energy with the distance in the central region of