and V. S. Stavinskiĭ for interest in the present work, and also to M. G. Yutkin, who participated in the preparation for the measurements.

[1] A. I. Abramov, Приборы и техника эксперимента (Instruments and Meas. Engg.) No. 4, 56 (1959).

[2] R. K. Adair, Phys. Rev. **86**, 155 (1952).

[3] Bransden, Robertson, and Swan, Proc. Phys. Soc. **A69**, 877 (1956).

Translated by J. G. Adashko
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ON THE PIONIC AND ELECTROMAGNETIC STRUCTURE OF NUCLEONS

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According to the Blokhintsev-Jastrow[1] model, the nucleon consists of a dense core and a more porous pion cloud. The basic states characterizing the electromagnetic structure of the nucleons are considered to be two- and three-pion states, whose diagrams are given in Fig. 1 (references 2 and 3).

The two-pion state can be easily calculated, but a rigorous calculation of the three-pion state is very difficult.[2] Therefore, we use phenomenological considerations to describe this state. Considering that the external field has a relatively weak influence on the nucleon structure, we disregard the presence of the photon (dotted line in Fig. 1). Then, instead of a two-pion state we get a one-pion state, described by the plain Klein-Gordon[4] equation (with a delta-function source). On going to the three-pion state we suppose that an emitted virtual pion which has gone a distance of $\sim \hbar/\mu c$ from the core makes a transition during its lifetime of $\sim \hbar/\mu c^2$ to a new, "polarized" state which reveals its structural properties (a bound nucleon-antinucleon pair, or "loop")* and through these interacts with the core, according to the Chew hypothesis, on the basis of a single-pion exchange.[5] One of the simplest diagrams of such a process is given in Fig. 1b.

Neglecting the photon, and supposing that the beginning (emitted) and the final (absorbed)

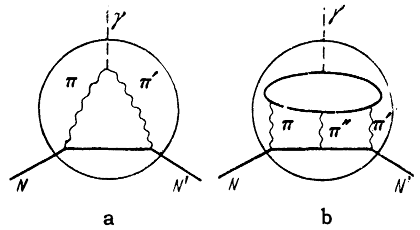

FIG. 1. a – two-pion state; b – three-pion state. Solid straight line – nucleon N; wavy line – virtual pion π; dotted line – photon γ.

pions are the same, we can write down the equation for the wave function Ψ of such a Π pion interacting with the core through a single-pion exchange, that is, by the Yukawa rule:

$$\Delta\Psi + (\hbar c)^{-2}[(E - V(r))^2 - (mc^2)^2]\Psi = 0,$$
$$V(r) = -(g_\Pi g_c/r)\exp(-\mu c r/\hbar); \quad (1)$$

the right side is zero, since nucleon regions far from the core are considered. The solution of this equation has the form[6,8]

$$\Psi = \exp[-i\varepsilon t/\hbar]\,Y(\vartheta,\varphi)\,R(r),$$
$$R(r) = \exp(-r/r_0)(r/r_0)^j w(r/r_0),$$
$$\varepsilon = \varepsilon(n); \quad j = -{}^1/_2 \pm \sqrt{(l + {}^1/_2)^2 - \beta^2}. \quad (2)$$

Here n is the principal quantum number; l, the orbital quantum number; $\beta = g_c g_\Pi/\hbar c$; g_c is the nucleonic charge of the core; g_Π, the nucleonic charge of the Π pion; $Y(\theta, \varphi)$ is the angular part of Ψ; and the function $w(r/r_0)$ goes rapidly to a constant a_0.

From $j \geq 0$ (Ψ has no pole at zero) we get $l \geq 1$, i.e., the lowest state of such a system is a p state. If the density of the Π-pion cloud $D = \Psi^2$, $j = 0$ (reference 3) then $g_\Pi \sim 0.1\,g_c$. If we consider that the mass of the Π-pion $m \sim M$, then it is necessary, in considering the core – Π-pion model, to take the core motion into account.[7] In the "semiclassical" approximation we get (according to Sommerfeld[7]) expressions for the wave functions of the Π pion and the core, Ψ_Π and Ψ_c, in the center of mass system and the corresponding densities

$$D_\Pi = C_\Pi \exp(-r/a_\Pi), \quad D_c = C_c \exp(-r/a_c), \quad (3)$$

where $a_\Pi \approx 0.23\,f$, $a_c \approx 0.2\,f$, and C_Π and C_c are constants (see reference 1).

The calculation of the mean square radius for the proton p and neutron n gives

$$\langle r\rangle_p^2 \approx \langle 0.76\,f\rangle^2, \quad \langle r\rangle_n^2 \approx \langle 0.19\,f\rangle^2$$
$$(1\,f = 10^{-13}\,\text{cm}). \quad (4)$$

The results in (3) and (4) agree with references 1 and 3.

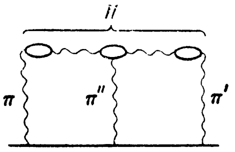

FIG. 2

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.

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

[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 $\omega t = 30$ (ω 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.