DECEMBER 1, 1937 PHYSICAL REVIEW VOLUME 52

On the Nature of Cosmic-Ray Particles

Y. NISHINA, M. TAKEUCHI, AND T. ICHIMIYA
Institute of Physical and Chemical Research, Tokyo
(Received August 28, 1937)

VARIOUS authors[1] have taken the view that cosmic-ray particles consist of two or more kinds of corpuscles. According to Compton and Bethe, and Auger,[1] the soft component near sea level is thus composed of electrons and the penetrating one of protons. Assuming the theory of showers by Bhabha and Heitler[2] and by Oppenheimer and Carlson[3] to be correct, we ought to be able to distinguish cosmic-ray electrons from protons, if they exist at all, by observing whether or not the particles suffer a large loss of energy and often produce showers on colliding with a lead plate of a suitable thickness.

We carried out such experiments with a lead bar 1.5 cm thick mounted in the middle of a Wilson chamber 40 cm in diameter, which is placed in a magnetic field of about 17,000 oersteds. The operation of the chamber is actuated by the coincidence of two Geiger-Müller tube counters mounted above the chamber, the distance between the counters being about 50 cm. The results showed that at sea level near Tokyo (geomag. lat. 25.4°N) about 10 to 20 percent of cosmic-ray particles of energies, high enough to produce coincidence in the strong magnetic field and pass through the Wilson chamber, consist of electrons and positrons, the rest being heavy particles, since they do not produce showers nor suffer much loss of energy in passing through the lead bar. Among the latter, however, we were

[1] A. H. Compton and H. A. Bethe, Nature **134**, 734 (1934); P. Auger, J. de phys. **6**, 226 (1935); C. D. Anderson and S. H. Neddermeyer, Int. Conf. on Physics, London **1**, 182 (1934); Phys. Rev. **50**, 268 (1936); J. Clay, Physica **3**, 338 (1936); L. Leprince-Ringuet, J. de phys. **7**, 70 (1936); J. Crussard and L. Leprince-Ringuet, Comptes rendus **204**, 240 (1937).

[2] H. J. Bhabha and W. Heitler, Proc. Roy. Soc. **A159**, 432 (1937).

[3] J. F. Carlson and J. R. Oppenheimer, Phys. Rev. **51**, 220 (1937).

surprised to find that there are some particles of both signs, which have much greater penetrating power for lead than protons of the same momentum ($H\rho$) would have. The specific ionization of some tracks is also much smaller than that of protons of the observed $H\rho$. These results can most naturally be explained, if one assumes the existence of new particles of a mass heavier than that of an electron and lighter than that of a proton. At about this time we received the paper of Street and Stevenson[4] and then that of Anderson and Neddermeyer[5] and saw that these authors had obtained similar results. Crussard and Leprince-Ringuet[6] also recognized the existence of particles, which lose less energy through matter than expected for electrons on the theory of showers and produce smaller specific ionization than protons of the same $H\rho$.

We have since then been trying to find a more exact value of the mass of the new particle. Since this seems hardly to radiate in collision with matter, we may for the moment assume that the loss of its energy in passing through lead is entirely due to ionization, although this is probably not always the case as will later be mentioned. In this respect the new particle behaves more like protons than electrons, and especially for energies higher than 10^9 ev we cannot discriminate between the two by specific ionization, because it becomes nearly the same for both. The range in lead, however, as a function either of $H\rho$ or of energy is sensitive to the difference of mass of the particles. We can thus draw a series of mass $H\rho$ curves for various values of ranges. By means of these curves, we can determine the mass of a particle, if we know its range and $H\rho$ from Wilson tracks. As the range we chose 3.5 cm of lead mounted in the middle of our Wilson chamber. In order to filter the electronic component of cosmic rays, a lead block 20 cm thick was inserted between the two controlling counter tubes, placed above the Wilson chamber as described before.

Until now we have obtained only one track which can probably be used for the determination of the mass. The initial value of $H\rho$ of the particle was 7.4×10^5 gauss-cm and after passing through lead it became 4.9×10^5 gauss-cm, showing the loss of about a half of the energy. The loss of energy by ionization and the range in lead calculated from the thickness of the lead bar and the final $H\rho$ are consistent, if we assume the mass in question of the particle to be 1/7 to 1/10 that of the proton. The above values of $H\rho$ and the specific ionization shown by the corresponding tracks are in accordance with the assumed mass. This value must necessarily be provisional and subject to a possible alteration. For accurate determination we need more tracks of appropriate energies.

From our present experimental results we cannot conclude whether the penetrating component of cosmic rays at sea level consists exclusively of these new particles or in part of protons. There are observed some particles which are stopped by 3.5 cm of lead and can be interpreted as protons on the mass $H\rho$ curve. On the other hand we observe some particles of high $H\rho$ which seem to be stopped by the lead plate. The ionization alone cannot account for such a large loss of energy, even if they are protons. We do not know as yet whether we have here to do with the presence of particles heavier than protons or with a certain type of loss of energy other than ionization for the new particles or for protons. The disintegration of lead nuclei caused by these particles must be taken into account in the problem, as can be seen from one of our photographs. Although the exact determination of the composition of the penetrating component of cosmic-ray particles has thus not yet been possible, its large part no doubt consists of the above new particles, through the existence of which various difficulties in connection with cosmic-ray phenomena e.g., ionization, radiative effect,[7] penetrating power, etc. now find a natural explanation.

We should like to express our gratitude to the Imperial Japanese Navy for kind assistances in carrying out these experiments and to Hattori Hokokwai Foundation for a financial grant. We are indebted to Mr. M. Kobayasi for theoretical discussions.

[4] J. C. Street and E. C. Stevenson, Bull. Am. Phys. Soc. **12**, No. 2, 13 (1937).
[5] S. H. Neddermeyer and C. D. Anderson, Phys. Rev. **51**, 884 (1937).
[6] J. Crussard and L. Leprince-Ringuet, J. de phys. **8**, 215 (1937).
[7] E. J. Williams, Phys. Rev. **45**, 729 (1934); *Kernphysik*, (Berlin, 1936), p. 123.

On the Mass of the Mesotron

Since we published[1] the results of mass determination of the mesotron, the existence of which had theoretically been foreseen by Yukawa, we have been continuing the same experiments with the Wilson cloud chamber.

During last September we obtained a photograph shown in Fig. 1. A lead bar 5 cm thick was mounted in the middle

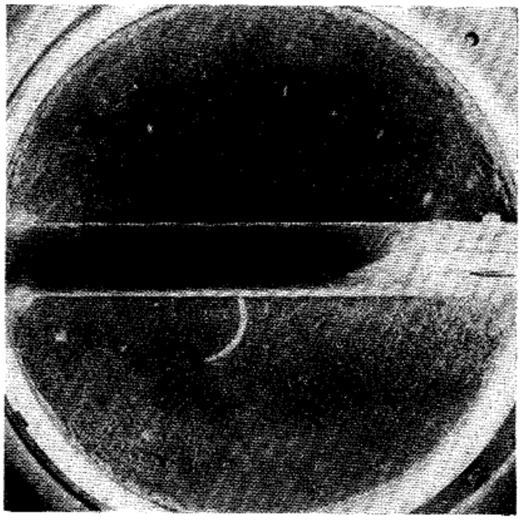

FIG. 1. Wilson track of a mesotron. $H = 12{,}600$ oersteds. $H\rho = 3.88 \times 10^4$ oersted·cm. Observed range = 6.15 cm.

of the chamber 40 cm in diameter, which is filled with air and alcohol vapor, and placed in a magnetic field of about 12,600 oersteds. The operation of the chamber was controlled by two Geiger-Müller tube counters mounted immediately above the chamber. The distance between the counters was about 15 cm. Above the counters was placed a lead block 20 cm thick.

A negatively charged particle of $H\rho = (3.88 \pm 0.08) \times 10^4$ oersted-cm seems to have been created within the lead bar by a certain non-ionizing agent and was brought to rest in the gas of the chamber, the observed range being 6.15 cm. By taking into account the pressure of the gas, which was between 1.23 and 1.30 atmospheres at 25°C, and a possible inclination of the track with respect to the plane of the chamber, we estimate its range in air of 15°C and 760 mm to lie between 7.3 and 8.1 cm. According to the range-energy curve for the proton given by Livingston and Bethe[2] we calculate the mass of the particle by using the above values of $H\rho$ and range and obtain

$$M_m = (170 \pm 9)m, \tag{1}$$

where m is the mass of the electron.

At the end of the range the photograph shows no sign of an electronic track, which would prove the disintegration of the mesotron.

We have recently re-examined the old photograph mentioned in our preceding paper[1] and obtained the following values. A positively charged particle of $H\rho = (7.4 \pm 0.1)$

$\times 10^5$ oersted·cm passes through a lead bar 3.5 cm thick at an angle of about 47°, the length of the path inside lead thus being 4.8 cm. After traversing the lead bar, $H\rho$ becomes $(5.0\pm 0.1)\times 10^5$ oersted·cm.

On assuming the mass of the particle, we can calculate its initial and final energies and thus find the loss of energy due to collisions within lead. On the other hand this energy loss can be calculated theoretically, for example, according to Bloch's formula,[3] if we use the assumed mass and the initial energy. The mass of the particle can be adjusted in such a way as to bring both values of the energy loss to agreement. In this manner we formerly obtained with the old data of preliminary measurements

$$M_m = (180\sim 260)m. \qquad (2)$$

In these calculations we assumed for Bloch's formula the maximum energy W transferred in a direct collision from the particle to a free electron to be $2mv^2$ according to the nonrelativistic theory, where v is the velocity of the particle. In our case, however, we ought instead to have used a relativistic value

$$W = \frac{2mM_m(1+\eta)E}{m^2+2mM_m\eta+M_m^2}, \qquad (3)$$

as was given by Bhabha,[4] where E is the initial energy of the particle, $\eta = (1-v^2/c^2)^{\frac{1}{2}}$, and c is the velocity of light. If we do this and use the above data of the new measurements, we obtain

$$M_m = (180\pm 20)m, \qquad (4)$$

which is in better agreement with the value (1).

A more detailed paper will be published in the Scientific Papers of this Institute.

Y. Nishina
M. Takeuchi
T. Ichimiya

Cosmic-Ray Sub-Committee of Japan Society for the Promotion of Scientific Research,
Institute of Physical and Chemical Research,
Tokyo, Japan,
January 31, 1939.

[1] Y. Nishina, M. Takeuchi and T. Ichimiya, Phys. Rev. **52**, 1198 (1937).
[2] M. S. Livingston and H. A. Bethe, Rev. Mod. Phys. **9**, 268 (1937).
[3] Cf. W. Heitler, *The Quantum Theory of Radiation* (Oxford, 1936), formula (1), p. 218.
[4] H. J. Bhabha, Proc. Roy. Soc. **A164**, 255 (1938).