On the Mass and the Disintegration Products of the Mesotron

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A photograph has been obtained of a mesotron of positive charge which comes to rest in the gas of a cloud chamber and ejects a positron of 24-Mev energy. Several possible interpretations of this photograph are discussed.

I. EXPERIMENTAL DATA

IN a recent series of cloud-chamber observations made at an elevation of 9200 meters in a B-29 airplane, a photograph (Fig. 1) was obtained in which a mesotron of positive charge was observed to come to rest in the gas of the cloud chamber and at the end of its path to produce a lightly-ionizing particle of positive charge. In two previous cases, cloud-chamber photographs have shown the track of a particle resulting from the disintegration of a mesotron.[1] Other observations have shown that mesotrons of negative charge may undergo absorption into a nucleus before disintegration, in the case of nuclei of high atomic number.[2] Recent observations of tracks produced by slow mesotrons in photographic emulsions show that secondary-charged mesotrons are also sometimes produced.[3] In no previous case, however, has it been possible to obtain an accurate measurement of the magnetic curvature of the disintegration particle.

In the photograph here reported, the disintegration particle has an $H\rho = 8.0 \times 10^4$ gauss cm in a magnetic field of 7500 gausses. The curvature of this particle is accurately measurable and is not influenced by multiple scattering in the gas. The incoming mesotron is increasingly scattered toward the end of its path. It has an apparent $H\rho = 2.0 \times 10^4$ gauss cm, a range in argon of 4.4 cm (reduced to N.T.P.), and makes an angle of about 60° with the magnetic field. The angle between the track of the disintegration particle and the incoming mesotron is approximately 90°.

If the disintegration particle is assumed to be a positron, its $H\rho$ corresponds to an energy of 24 Mev. The magnetic curvature of this particle, together with the low value of its specific ionization, places an upper limit on its mass equal to about 25 electron masses, and so is quite consistent with the assumption that it has a mass equal to that of an electron.

II. DISINTEGRATION RESULTING IN PRODUCTION OF ELECTRON AND NEUTRINO

The mass of the mesotron is directly related to the energy of disintegration. It usually has been assumed that the mesotron disintegrates into an electron and a neutrino, and that the loss in rest mass which occurs in the transformation appears as additional kinetic energy of the electron and neutrino (or photon) in conformance with conservation of energy and momentum.

The disintegration of a mesotron into an electron (+ or −) and a neutrino has been compared with ordinary β-disintegration, but one difference should be noted. In the case of ordinary β-disintegration, for a given available disintegration energy, the electron may be emitted with any energy between zero and the available disintegration energy, with the emission of a single neutrino. Charge and spin are conserved. Conservation of energy and momentum are satisfied because a daughter nucleus is always present to absorb the recoil and thus balance the momenta of the electron and neutrino. In the case of mesotron disintegration, however, the assumption has usually been made that the mesotron disappears entirely, and so for a given available disintegration energy (here dependent upon the mass of the mesotron) the disintegration electron can

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[1] Williams and Roberts, Nature **145**, 102 (1940); Shutt, de Benedetti, and Johnson, J. Frank. Inst. **235**, 637 (1943).
[2] See Conversi, Pancini, and Piccioni, Phys. Rev. **71**, 209 (1947).
[3] Lattes, Muirhead, Occhialini, and Powell, Nature **159**, 694 (1947).

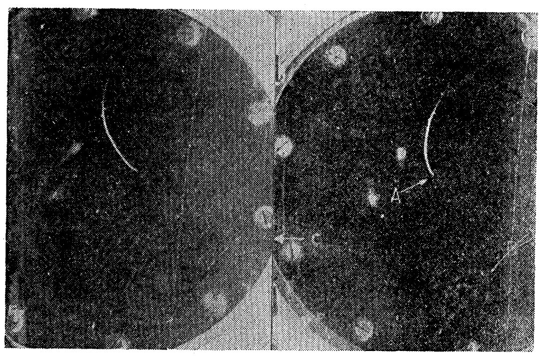

FIG. 1. A mesotron enters the cloud chamber through the rear wall and disintegrates in the gas giving rise to a positron of 24 Mev. The terminus of the mesotron track is at A. The disintegration particle leaves the right-hand photograph at B, and the left-hand photograph at C. The faintness of the positron track is due to its position near the edge of the illuminated region of the chamber. (The track passing from top to bottom of the photograph was produced by the particle which triggered the cloud chamber, the mesotron disintegration occurring by chance at about the same time.)

appear only with a unique energy, on the assumption that only one other known particle (neutrino or photon) is emitted. Thus in the case here reported, the assumption that two known particles, *viz.*, an electron and a neutrino (or photon), are produced in the disintegration requires that the mass of the mesotron lie between the limits of 90 and 110 electron masses.

It is possible, of course, that the mesotron disintegrated in the proximity of a nucleus under conditions such that the nucleus could absorb an appreciable recoil. In this way an energy of the disintegration electron of 25 Mev and a mesotron mass of 200 electron masses could be brought into harmony with conservation of momentum and energy. Such a possibility, however, seems quite unlikely, since the incoming mesotron is of positive charge and has a very low energy, as shown by its heavy degree of ionization, by its large curvature, and by the large degree of scattering in the gas.

III. THE MASS OF THE MESOTRON

Direct determinations of the mass of the mesotron have been reported, usually based on experiments in which two of the following parameters were measured: range, specific ionization, and magnetic curvature. In many cases these experiments could not lead to reliable numerical values of the mass of the mesotron because it was not possible to obtain accurate measurements of at least two of the above parameters in any given case. The specific ionization was often only a rough estimate, or the effects of multiple scattering of the particle under the conditions of the experiment were often sufficiently large to impair the measurement of the magnetic curvature.[4]

Data which have been obtained so far, and which are not subject to the above criticism, lead to a value for the mass of the mesotron of about 200 electron masses. The first and most accurate such determination,[5] in which a mesotron was observed to pass through a Geiger counter placed horizontally across the diameter of a cloud chamber, and come to rest in the gas of the cloud chamber, gave a value for the mass of 220 electron masses with a possible error conservatively estimated as ± 35 electron masses. In this case multiple scattering of the mesotron was not an important error, and both the magnetic curvature and range were accurately determined.

Additional determinations,[6] and in particular a set involving 26 individual cases,[7] by a method similar in principle to the above, and made under conditions where multiple scattering is not an important error, are also consistent with a mass equal to about 200 electron masses.

An accurate, direct determination of the mass of the mesotron in the present case cannot be made. Although the radius of curvature and the range of the particle would seem to indicate a mass of about 100 electron masses, the probable effects of multiple scattering on the observed curvature are such that a mass as large as 200 electron masses cannot be excluded. The probability of occurrence of sufficient multiple scattering to make a mass of 200 electron masses appear to be 100 electron masses is 20 percent. For an assumed mass of 300, the probability is 5 percent.[4]

[4] H. A. Bethe, Phys. Rev. **70**, 821 (1946).
[5] Neddermeyer and Anderson, Phys. Rev. **54**, 88 (1938); Rev. Mod. Phys. **11**, 201 (1939).
[6] Donald J. Hughes, Phys. Rev. **71**, 387 (1947).
[7] William B. Fretter, Phys. Rev. **70**, 625 (1946).

IV. THE GENERAL CASE OF DISINTEGRATION INTO TWO PARTICLES

In view of the fact that the reliable and direct determinations of the mass of the mesotron seem in all cases to indicate a mass considerably greater than 100 electron masses, and that the curvature and range of the incoming mesotron in the present case are not inconsistent with a larger mass, one may assume that the mass of the mesotron here observed is actually considerably greater than 100 electron masses. For the sake of discussion let us take a mass equal to 200 electron masses. We shall assume, further, that only two particles, one charged and one neutral, are produced in the disintegration. The observed curvature and specific ionization of the charged particle produced in the disintegration place an upper limit on its mass equal to about 25 electron masses. If, for the time being, we dismiss the possibility that the mass of the charged particle lies between 1 and 25 electron masses, and assume it has electronic mass, then the mass of the neutral particle, computed on the basis of conservation of momentum and energy, must have a value of about 140 electron masses, and its kinetic energy must be about 4 Mev.

The difference between the masses of the primary particle and of the secondary "heavy" particle, namely, about 60 electron masses, and also the kinetic energy of the secondary particle are relatively insensitive to the assumed mass of the primary particle; e.g., if a mass of 300 electron masses is chosen for the primary particle, the mass difference between the primary mesotron and the secondary neutral mesotron is 55 electron masses, and the kinetic energy of the secondary neutral mesotron is about 2 Mev.

The above interpretation shows an analogy with the recent observations by Lattes, Muirhead, Occhialini, and Powell[3] of tracks of secondary charged mesotrons in photographic emulsions. In two instances, the track of a secondary mesotron was observed to originate at the terminus of the track of another mesotron which comes to rest. If, among the interpretations suggested by the authors, we choose the fundamental one in which a charged mesotron disintegrates into another charged mesotron and a photon (or neutrino), we note that, in each case, the difference in mass between the primary and secondary mesotron is "not greater than 100 electron masses," its kinetic energy is about 2 Mev, and the total disintegration energy is "of the order of 25 Mev." The following points of similarity between the results of Lattes, Muirhead, Occhialini, and Powell and our own observation are now apparent: the mass difference between the original and the secondary mesotrons, the kinetic energy of the secondary mesotron, and the total disintegration energy of the process.

V. DISINTEGRATION INTO MORE THAN TWO PARTICLES

The possibility that the mesotron actually has a mass greater than about 100 electron masses and disintegrates into more than two particles should not be overlooked. If the spin of the mesotron is either zero or unity, it may disintegrate, for example, into an electron, a photon, and a neutrino. If the spin of the mesotron is one-half, the disintegration products may be an electron and two neutrinos, or an electron and two photons. In terms of an assumption of this kind, the electron may be emitted with any energy within a range between zero and an upper limit which depends upon the mass of the mesotrons, and still permit the conservation of both energy and momentum. In such a case, then, there would be no contradiction between an energy of 25 Mev for the disintegration electron, and a value of mass of the mesotron greater than 100 electron masses.

VI. MESOTRON OF NEGATIVE CHARGE

Inasmuch as the lower half of the mesotron track exhibits considerably more scattering than the upper half, it seems very unlikely that the mesotron could be of negative charge and traveling upward. Any interpretation based on this possibility will not be discussed at this time.

VII. CONCLUSION

Until more data are obtained it is not possible to state with certainty which of the interpretations discussed above represents the correct one. This is particularly true since the present experiments were carried out at a higher elevation above sea level than most previous work.

Our present knowledge of the properties of mesotrons, however, would seem to support the view that the photograph here described represents the disintegration of a charged mesotron into an electron and a neutral particle smaller in mass than the charged mesotron by 50 to 60 electron masses. In terms of this interpretation, the mass of the incoming mesotron can well be of the order of 200 electron masses, a value which is in complete accord with the best previous mass determinations. There is also a quantitative agreement, within the uncertainty of the measurements, between the data of Lattes, Muirhead, Occhialini, and Powell, in the only two cases so far reported by them, and our own observation, with respect to (a) the kinetic energy of the secondary mesotron, (b) the mass difference between the initial and secondary mesotron, and (c), the disintegration energy. The mechanism of disintegration of a charged mesotron into an electron and a neutral mesotron is closely analogous to that of a charged mesotron into a photon (or neutrino) and a secondary-charged mesotron. In the former case the electric charge is associated with the "light" secondary particle, and in the latter with the "heavy" secondary particle. The disintegration of a mesotron into an electron and a neutral mesotron would, of course, escape detection by the photographic emulsion technique, since neither of these particles would there produce an observable track.

The existence of neutral mesotrons would aid in removing the present difficulties in explaining the proton-proton and proton-neutron scattering experiments which imply a charge independence of nuclear forces. The existence of two types of mesotrons of different masses already has been suggested on theoretical grounds.[8]

In any case, it is very strongly suggested that a complete interpretation of the experimental data is not to be found in the simple assumption of unstable particles with unit charge and a *unique* mass of the order of 200 electron masses.

It will be of great interest to obtain further measurements of the energy of the disintegration particles and, in particular, under conditions where the mass of the primary mesotron can be determined directly.

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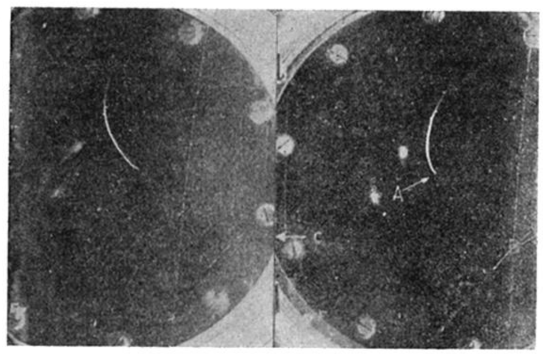
[8] J. Schwinger, Phys. Rev. 61, 387 (1942).



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