Cloud-Chamber Observations of the New Unstable Cosmic-Ray Particles *

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Thirty-four "forked tracks" similar to two previously reported by Rochester and Butler have been observed in 11,000 cloud-chamber photographs of cosmic-ray penetrating showers, confirming their conclusion that new unstable neutral and charged particles exist. The lifetime of the neutral particles is found to be about 3×10^{-10} sec., and some information as to the nature of the decay products is given.

1. INTRODUCTION

IN a series of 11,000 cloud-chamber photographs made in a study of penetrating showers, 34 "forked tracks" were observed of the two types previously reported by Rochester and Butler.[1] To interpret these photographs one must come to the same remarkable conclusion as that drawn by Rochester and Butler on the basis of their two photographs; *viz.*, that these two types of events represent, respectively, the spontaneous decay of neutral and charged unstable particles of a new type.

The conclusion that the phenomena actually represent decay processes follows from arguments similar to those previously given by Rochester and Butler. The larger number of events observed in these experiments greatly strengthens these arguments, and thus establishes more firmly the existence of the new unstable particles.

Of our 34 cases, 30 show the decay of a neutral particle resulting in the production of two charged particles, and 4 show the decay of a charged particle resulting in the production of a second charged particle and presumably a neutral particle. We shall refer to these two types of events as decays of the *first* and *second* kinds, respectively. It is possible, of course, that in each type of decay additional neutral particles are also produced.

The cloud chamber used in these experiments was previously employed in measuring the momentum spectrum of the decay particles of μ-mesons.[2] A lead plate 2 cm thick was placed across the horizontal diameter of the chamber, and lead blocks of 20-cm total thickness were placed above the chamber. The chamber, 30 cm in diameter, was in a magnetic field of 6500 gauss, but in the majority of cases track distortions prevent accurate determinations of the momenta of the particles. An arrangement of Geiger counters sensitive to penetrating showers was used to actuate the chamber.

Six decay events (all of the first kind) were observed in 3000 photographs made at Pasadena at 230 meters elevation, and 28 decay events (24 of the first kind and 4 of the second kind) were observed in 8000 photographs made on White Mountain, California, at 3200 meters elevation. Of the Pasadena and White Mountain exposures, about 20 percent and 30 percent, respectively, show showers of penetrating particles; i.e., showers containing two or more roughly collimated, lightly ionizing particles of momentum above 200 Mev/c, of which at least one penetrates the lead plate without evidence of radiative collisions.

Estimates of the specific ionization show that all the charged particles observed in the decay events have a charge equal to that of one electron.

2. DECAY EVENTS OF THE FIRST KIND

A decay of the first kind is characterized by two tracks which form an angle whose vertex is in the gas and whose sides usually extend downward. The angles are distributed between 3.5° and 126°, and are less than 40° in 17 cases. In the great majority of cases the ionization is indistinguishable from the minimum for singly charged particles, and the momenta are above 200 Mev/c. In a few cases, however, especially where the angles are large, the tracks show appreciable curvature and an ionization up to ten times minimum.

Nineteen photographs which show decay events of the first kind also show tracks of additional time-associated particles. In 15 cases, where the orientation of these other tracks determines the position of the nucleon impact in which the particles originated, the orientation of the decay tracks suggests that the unstable neutral particle originated in the same nucleon impact. If the only particles which result from the decay of the unstable neutral particle are the two charged particles which produce the tracks, then the plane defined by these tracks should contain the position of the nucleon impact. In 12 cases this condition is fulfilled within the accuracy of the measurements, but the accuracy is not quite sufficient to rule out the possibility that neutral particles are produced in decays of the first kind.

In one decay of the first kind in which the track of one of the secondary particles was unusually long and of high curvature, the observed ionization and the curvature in the magnetic field place the mass of the particle between 150 m_e (electron masses) and 350 m_e. In five other cases it was similarly found that the mass of one of the particles is less than that of a proton. In

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[1] G. D. Rochester and C. C. Butler, Nature **160**, 855 (1947).
[2] Leighton, Anderson, and Seriff, Phys. Rev. **75**, 1432 (1949).

no case could limits be placed on the mass of *both* charged secondary particles by this method.

In six decays of the first kind in which secondary particles penetrate the 2-cm lead plate, including three cases in which both secondary particles penetrate the plate, there is no evidence of the production of electron secondaries through radiative collisions. Since the particles all had high momenta, this indicates that neither of the charged decay products is as light as an electron.

The angle of scattering of eight of the secondary particles in the 2-cm lead plate is 10° or less, but in one case an angle of 35° was observed. Since the latter angle can hardly be attributed to Coulomb scattering, a strong nuclear interaction is indicated. The fact that another of the particles is observed to produce a disintegration in the lead plate is additional evidence of a strong nuclear interaction. Two nuclear events in ten traversals of the lead plate correspond to a cross section in lead of about 10^{-24} cm^2. However, there is as yet no evidence that *both* secondary particles have strong nuclear interaction.

The above results do not serve to identify completely the two charged particles which result from the decay of the unstable neutral particles. In terms of known particles, possibilities are (a) two π-mesons, (b) a π- and a μ-meson, or (c) a proton and a meson (π or μ).

The mass of the unstable neutral particles can in principle be calculated on the assumption that only two particles are produced in the decay. Actually, in each case, because of limitations in the determination of momentum, only upper and lower limits could be placed on the mass. Even within these limits it has not been possible so far to find a single value of the mass consistent with all the cases. However, in no case do the data require the mass of the neutral particle to be more than 250 m_e above the sum of the masses of the decay products if these are both mesons, or more than 400 m_e above the sum of the masses if one of the products is a proton. It is possible that the inconsistencies in the mass value may be removed by more complete measurements; of course, the mass calculated in this way cannot be expected to have a single value if neutral secondaries also result from the decay, or if the unstable neutral particles observed have several different masses, such as might be imagined to correspond to different "excited states" of a neutron.

The distribution of the decay points along the lines of flight of the neutral unstable particles was used to estimate the rest lifetime of these particles. Allowance was made for the variation in path length resulting from the geometry of the cylindrical chamber, and the relativistic time dilatation factor was estimated for each case. The mean rest lifetime so obtained is $(3\pm2)\times10^{-10}$ sec.

This lifetime, and the geometry of the apparatus, then permit one to estimate that about 1/10 of the unstable neutral particles produced in the lead blocks, whose lines of flight pass through the chamber, decay inside the chamber. Thus there must have been about 300 such unstable particles produced in the same events which gave rise to the 10,000 ionizing penetrating-shower particles observed in the same series of photographs. That is, the number of unstable neutral particles produced in penetrating showers is about 3 percent of the number of ionizing particles.

3. DECAY EVENTS OF THE SECOND KIND

A decay event of the second kind is characterized by the appearance of a sharp deflection in a track having small curvature, without the appearance of a recoil track. This has been interpreted[1] as showing the decay of a charged particle at the deflection point. In the four cases so far observed, the values of the angular deflection between the two segments of the track are 7°, 15°, 34°, and 40°. In all the decays of the second kind the tracks are short and only a lower limit of 200 Mev/c can be placed on the momenta. In one case, the charged secondary particle penetrates the 2-cm lead plate with no indication of a radiative collision in the plate. This observation and a similar one by Rochester and Butler indicate that the mass of the charged secondary particle is greater than that of an electron.

If the two types of unstable particles had the same mean lifetime, then for each type the number observed to originate in the lead above the chamber and the number observed to originate in the plate inside the chamber should be approximately in the same ratio. Actually, this ratio is quite different for the two types, being 25:5 for decays of the first kind and 1:3 for decays of the second kind. The relative paucity of unstable charged particles observed to originate in the lead blocks indicates that these particles have a shorter mean lifetime than the neutral particles, and are therefore more likely to decay before traversing the distance (about 15 cm) between the lead blocks and the chamber than are the neutral particles. On the other hand, the approximate equality of the number of each kind of particle observed to originate in the lead plate (3 charged *vs.* 5 neutral) suggests that the two kinds of unstable particles are produced in comparable numbers.

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