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ANOMALOUS DECAYS OF HYPERFRAGMENTS

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Two events of K-meson decay of hyperfragments are described. They are compared with previously described hyperfragment-decay events and some common features are noted. It is shown that the events cannot be explained by statistical deviations of the characteristics of the particle tracks in the emulsion.

SEVERAL events of hyperfragment decay have been recently described, in which a particle is emitted from the point of decay, with a mass equal to the K-meson mass[1-5] within the limits of measurement error. There are also known events of decay of hyperfragments with anomalously large values of liberated energy, which cannot be attributed to the decay of the bound Λ^0 particle.[6,7]

As a result of a systematic scanning of two emulsion chambers, one exposed to cosmic rays in the stratosphere and the other to pions of energy on the order of 4.5×10^9 ev, the authors have observed three events in which a particle with mass close to the K-meson mass was emitted from the stopping point of the heavy fragment. One of these cases was described earlier,[4] and the two others are described here.

The cases described were observed in an emulsion chamber, made up of layers of G-5 emulsion, exposed to pions of energy 4.5×10^9 ev, among 60,000 stars with $N_h \geq 8$. In both cases these particles stopped in the emulsion without any visible phenomena at the end of the track. We give here detailed descriptions of these cases.

Case 1. (Microphotograph shown in Fig. 1). Primary star of type $18 + 2\pi$. Particle F, emitted from this star, decays after a range of $101\,\mu$ in emulsion with emission of two charged particles 1 and 2. The dip of F in the unprocessed emulsion amounts to 5° 20′ ± 30′. Measurements of the width along the track of F have disclosed a tapering zone 65 to $76\,\mu$ long. According to references 8 and 9, the charge of the particle has been found to be $(8 \pm 2)e$, where e is the electron charge. The average width of the track in the portion where there is no tapering, equal to $(1.065 \pm 0.054)\,\mu$, does not contradict this result.

The tracks of particles 1 and 2 terminate in the emulsion with ranges of (61 ± 0.4) and $(9362 \pm 122)\,\mu$, respectively. The angle between the tracks of particles 1 and 2 is 83° 50′ ± 1° 20′.

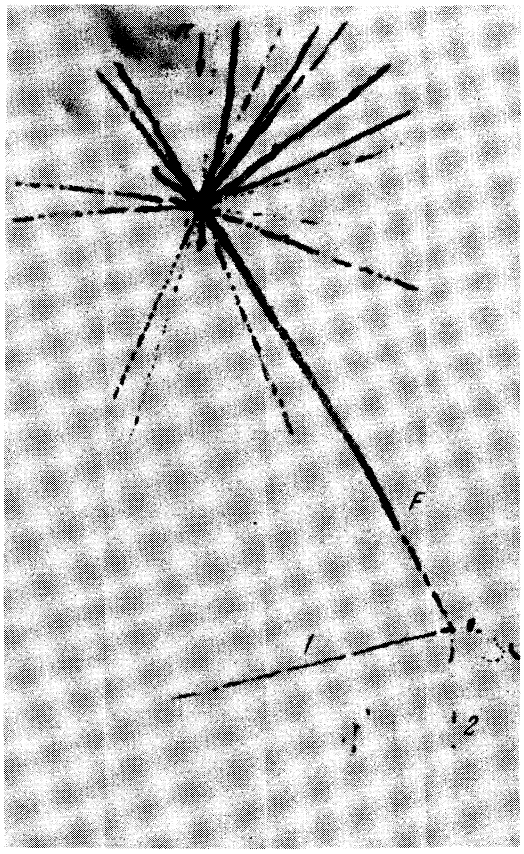

FIG. 1

A comparison of the width of track 1 with the widths of the tracks of an α particle, a lithium nucleus, and a proton, taken in the same plate and having approximately the same inclination, shows that the charge of particle 1 is equal to 2. If we consider track 1 to belong to an α particle, its energy and momentum are respectively (11.1 ± 0.1) Mev and (250 ± 1) Mev/c.

The mass of particle 2 was determined by two methods: by the range-scattering method and by the range-ionization method. The angle of multiple scattering was measured both by the method of constant cells, and by the method of constant inclinations.[10] The measurements were carried out by three observers and gave compatible results. The measurements with doubled intervals indicate the absence of a noticeable influence of noise on the result of the measurements. The width of the distribution curve of the second differences agrees well with the quantity predicted by the multiple-scattering theory.

The ionization was determined by comparing the density of the gaps in track 2 with the density of gaps in the tracks of the proton and pion, taken in the same plate.[11] The values of the mass of particle 2, obtained by these methods, coincide with each other and are equal to $M(J, R) = (856 \pm 167)\, m_e$ and $M(\langle\alpha\rangle, R) = (990 \pm 120)\, m_e$, respectively.

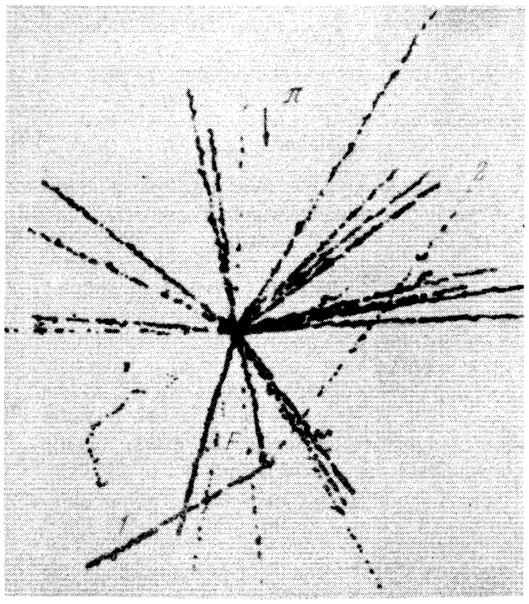

FIG. 2

Considering particle 2 to be a K meson, its energy and momentum were found to be respectively (38.3 ± 0.3) Mev and (197.6 ± 1.4) Mev/c. The minimum total momentum of particles 1 and 2 was found to be (307 ± 1.4) Mev/c. Assuming this momentum to be carried away by the residual nucleus, a track of this nucleus should be seen in the direction opposite to the direction of the total momentum of particles 1 and 2; this, however, was not observed. Starting with this fact, the most probable of all the decay schemes considered for particle F are found to be the following

$$^{*}C_6^{14} \rightarrow \mathrm{He}_2^3 + K^- + n + \mathrm{B}_5^{10};\quad ^{*}\mathrm{O}_8^{18} \rightarrow \mathrm{He}_2^3 + K^- + n + \mathrm{N}_7^{14}.$$

In all other schemes considered, either emission of neutrons is impossible, or the residual nucleus is found to be radioactive.

Case 2. Primary star of type 19 + 3π. Emitted from the primary star is the particle F, which decays after a range of 28 μ with emission of two charged particles 1 and 2 (Fig. 2).

The track of the particle F is inclined to the plane of the emulsion by 4° 40′ ± 1°. The track has two gaps 0.3 and 0.7 μ long. At the end of the range the track is strongly scattered. The width of the track of F is equal to the width of the tracks of singly-charged particles and is substantially less than the width of the tracks of particles with charge more than 1 (α particle and lithium nucleus). The tracks of particles 1 and 2 terminate in emulsion after ranges of (465 ± 8) and (13,640 ± 170) μ, respectively. The spatial angle between particles 1 and 2 is 141° ± 1° 30′.

The track of particle 1 was identified, by the density of gaps and by its width, as belonging to a particle of charge 2. The mass of particle 2 was determined from measurements of the average angle of multiple scattering, ionization, and range. Particular attention was paid to the reliability of measurements. The measurements were carried out by several observers, whose results coincided within the limits of errors.

The scattering was measured both by the method of constant cells, and by the method of constant inclinations. The effect of noise on the measurement results was first ascertained and was found to be negligibly small. The width of the distribution curve of the moduli of the second differences was within the limits of the predictions of the theory of multiple scattering. The ionization was determined by counting the grains and measuring the gap densities. In the second case a comparison was made of the corresponding quantity for track 2 and for control pions.

As a result of the measurement, the following values of the mass of particle 2 were obtained:

$M(J, \langle\bar{\alpha}\rangle) = (801 \pm 143)\, m_e$ —grain count;
$M(J, R) = (1170 \pm 120)\, m_e$ — gap density;
$M(\langle\bar{\alpha}\rangle, R) = (986 \pm 132)\, m_e$ —method of constant inclinations (c.i.)
$M(\langle\bar{\alpha}\rangle, R) = (764 \pm 170)\, m_e$ —method of constant cell.

From a comparison of the charges of particle F and of particle 1 it follows that $A_F = 3$ or 4, while $A_1 = 3$ or 4, where A_F and A_1 are the mass numbers of particles F and 1. The presence of the considerable residual momentum in particles 1 and 2, however, shows that this momentum should be compensated for by some neutral particle, emitted from the secondary star. It follows, therefore, that the only possible value of the mass numbers of particles F and 1 are $A_F = 4$ and $A_1 = 3$. Then the total momentum of particles 1 and 2 will be (294 ± 4.5) Mev/c, and the decay scheme of the particle will be

$$^*\mathrm{H}_1^4 \to \mathrm{He}_2^3 + K^- + n + Q.$$

The total energy liberated, considering the neutral particle to be a neutron, will be (110.4 ± 1.6) Mev (without allowance for the mass of the K meson proper).

Together with the decays described above, there are literature data on seven cases of K-meson decays of hyperfragments. In six of these cases the particle identified as the K meson stops in the emulsion, and in none of these cases is the stopping of this particlee accompanied by phenomena characteristic of the stopping of K mesons. It follows therefore that these particles are not K mesons and, like the muon, become absorbed in the nucleus without giving a visible disintegration. In case 4, however,[2] the particle identified as a K meson is absorbed in flight, indicating that this particle interacts strongly with the nucleus, although in this case no visible disintegration is observed. The identification of these particles is based only on the analysis of the characteristics of the particle tracks in the emulsion, and in all cases the masses determined on the basis of different characteristics of the track (the ionization-range, scattering-range, and scattering-ionization methods) agree with each other.

The most trivial explanation of these cases could be one in which all these particles are protons, but as a result of statistical deviations of the characteristics of their tracks in the emulsion, the mass measured is found to be close to that of the K meson, although under this assumption one cannot explain cases with anomalously large liberated energy (~ 500 Mev). This can occur when a correlation exists between the deviations of the different characteristics of the proton track, causing the proton masses, measured on the basis of any track characteristic, to be shifted to one side. If the foregoing assumption is correct, the probabilities of appearance of the discussed number of such events among the approximately 300 known* "normal" cases of mesonless decay of hyperfragments correspond to the number of observed cases.

To verify the foregoing assumption concerning the connection of the deviations of the track characteristics of the particle in the emulsion, we measured the masses of 140 known protons. The protons were taken from σ stars, produced by negative pions, which were identified visually. We choose only σ-star tracks with a residual range not less than 2500 μ and a dip angle to the plane of emulsion not more than 10 — 15°. In each individual case the mass of the particle was measured simultaneously by two methods: by the range-scattering method and by the range-ionization method. The average angle of multiple scattering was determined by the c.i. method with a cell for the proton;[10] the ionization was estimated from measurements of the density of the gaps of the measured track and by comparison of the density of the gaps of control pions, which were identified by the π-μ-e decay.[11]

Among the 140 investigated particles, there was not a single case where the statistical deviations caused the measured mass to be close to the mass of the K meson in either method of mass measurement.

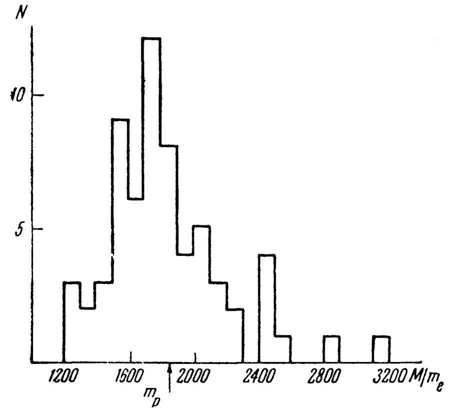

FIG. 3. Distribution of the masses of particles measured by the [$\langle\bar{\alpha}\rangle$, R] method, for particles, the mass of which as given by the [g, R] method is greater than the proton mass.

To clarify the existence of a correlation between the deviations of the values of the measured mass from the proton mass in these two methods of measurements, we have compared the distribution of the masses measured by the scattering-range method, for particles whose mass, measured by the range-ionization method was greater (Fig. 3) or else smaller (Fig. 4) than the proton mass. The satisfactory agreement of these distributions indicates that there is no correlation between the deviations of the multiple scattering and the ionization.

The probability of random coincidence between the values of the proton mass and the mass of the K meson with accuracy of 400 m_e in the two meas-

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*The number of known "normal" mesonless decays with emission of a fast proton does not amount to even half this number.

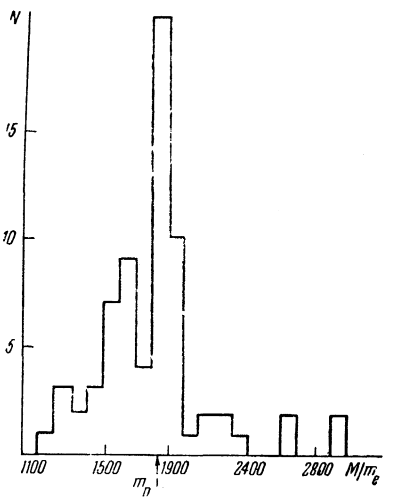

FIG. 4. Distribution of the masses of particles, measured by the [<$\bar{\alpha}$>, R] method, for particles whose mass is less than the proton mass when measured by the [g, R] method.

urement methods amounts according to our data to less than 0.5%, i.e., such a coincidence cannot explain more than one of the discussed cases. These data show that it is very unlikely that statistical deviations of the track characteristics can explain these cases.

A summary of the data on K-meson decays of hyperfragments is listed in the table. An analysis of the secondary stars shows certain singularities, which are common to all cases. With the exception of case 4 (reference 2), in all the other cases of K-meson decay of hyperfragments, the kinetic energies of the particles, identified as K mesons, are quite close to each other.

In all the cases discussed, the summary momentum of the charged particles is not equal to zero under any assumptions concerning the nature of the secondary particles, which is evidence that in these cases some neutral particles are emitted. In all cases where the unbalanced momentum can be estimated, the values of these momenta are close to each other. It follows, therefore, that in these cases we deal, perhaps, with a two-particle decay of some charged particle.

It follows, therefore, from the foregoing analysis of the anomalous cases of hyperfragment decay, that the particle emitted from the point of decay of the fragments has a mass on the order of 1000 m_e and its properties differ from those of K mesons.

Number of events	Literature reference	Mass of particle in m_e and method of determination of mass	Particle energy, Mev	Unbalanced momentum, Mev/c
1	Present work	$[856\pm167]$; $[J,\ R]$ $[990\pm120]$; $[\langle\bar{\alpha}\rangle,\ R]$	38.3±0.3	307±1.4 or 335±2
2	Present work	$[801\pm143]$; $[J,\ \langle\bar{\alpha}\rangle]$ $[1170\pm120]$; $[J,\ R]$ $[986\pm132]$; $[\langle\bar{\alpha}\rangle,\ R]$ $[764\pm170]$; c.i. method	48.1±0.2	294.5±4.5
3	[1]	$[1103\pm190]$; $[R,\ J]$ $[759\pm239]$; $[\langle\bar{\alpha}\rangle,\ R]$ $[1092\pm170]$; $[J,\ \langle\bar{\alpha}\rangle]$ $[1170\pm200]$; c.i. method	43.8	not less than 200
4	[2]	$[1160\pm180]$; $[J,\ \Delta R]\pi$ $\left[80^{+400}_{-180}\right]$; $[g,\ \Delta R]\pi$ $\left[950^{+330}_{-120}\right]$; $]J,\ \Delta R]p$	65±5	
5	[3]	$[850\pm300]$; $[J,\ R]$ $[1200\pm320]$; $[\langle\bar{\alpha}\rangle,\ R]$	50.0	
6	[4]	$\left[725^{+170}_{-140}\right]$; $[J,\ \langle\bar{\alpha}\rangle]$ $[700\pm85]$; $[1380\pm150]$;	46±4	337±21 or 463±25
7	[5]	$[1005\pm200]$; $[\langle\bar{\alpha}\rangle,\ R]$ $[1024\pm150]$; $[\bar{J},\ R]$	42.0	207.0

In conclusion, the authors consider it their pleasant duty to thank M. I. Podgoretskiĭ for continuous interest and for useful advice in the performance of this work.

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