A Summary of *K*-Meson Data

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The results of experiments on *K* mesons performed at the École Polytechnique of Paris and at the Massachusetts Institute of Technology are summarized and analyzed.

THE cosmic-ray groups at the École Polytechnique of Paris (E.P.) and at the Massachusetts Institute of Technology (M.I.T.) have recently reported new experimental data on charged heavy mesons (*K* mesons). These observations which refer to *K* mesons decaying at rest (*S* events) or in flight (*V* events) and giving rise to single charged secondary particles concur to establish the following results:

(1) The masses of *K* mesons observed to disintegrate at rest in photoemulsions or in cloud chambers are the same within the experimental errors. E.P. has made two different sets of measurements. The first set refers to *K* mesons emerging from stars and stopping in the emulsion;[1] the mean of six independent measurements obtained on three long tracks (three by scattering range and three by ionization range) gives a mass of $(940\pm40)m_e$. The second set refers to *S* events observed at the Pic du Midi with an arrangement of two cloud chambers.[2] The magnetic curvature of the track was measured in the top chamber, and the range in a multiplate chamber placed below. Three *S* events gave the mass values 885, 915, 1030; the mean of these three measurements is very close to the one quoted above.

M.I.T. analyzed (by the range-scattering method) 16 *S* events; under the assumption that all particles were identical, the most probable value of the mass turned out to be $(1200_{-200}^{+270})m_e$. Moreover, the distribution of the scattering variable for those cases where the *K* particles stopped after traversing 4 or more plates was found to be consistent with a single mass of about $1000m_e$.[3]

(2) There is evidence for the direct production in nuclear interactions of *K* mesons (3 events observed in emulsion by E.P.,[1] similar to that observed first by Levi-Setti and Tomasini;[4] several *S* events observed in cloud chambers by M.I.T. and E.P.).

(3) *K* mesons which decay at rest in cloud chambers have a mean life greater than 10^{-9} sec. Those that decay at rest in emulsions have a mean life greater than 10^{-10} sec. There is no evidence that the two mean lives are different.

(4) E.P. and M.I.T. do not find any evidence for the presence of π mesons among the decay products of *K* mesons. The presence of such particles, however, is not ruled out. On the other hand, there is some evidence that the secondary charged products of *K* particles decaying at rest or in flight are, for the most part at least, μ mesons. In the *S* events observed at M.I.T., the charged products traversed a total thickness of about 950 g cm^{-2} of lead without clear evidence of nuclear interaction.[3] This result appears significant, even if one allows for an observational bias against the detection of nuclear interactions. M.I.T. found one case where the secondary charged product originating from a *V* event is a π meson;[5,6] this particular *V* event, however, could well represent the decay of a particle heavier than a proton. E.P. has observed in emulsions two *K*-meson secondaries which are probably μ mesons. Moreover, charged *V*-event secondaries were observed to traverse, in a multiplate chamber, a total thickness of material equal to 1.8 times the geometric collision mean free path;[2] no interaction was detected in the traversals of these fast particles.

(5) The charged decay products of *K* mesons found in *S* and charged *V* events do not form mono-energetic groups. M.I.T. found two *S* events in which the decay products traversed more than 73 and more than 85 g cm^{-2}, respectively.[3] The momentum corresponding to 85 g cm^{-2} Pb is 210 Mev/*c*, if the secondary particle is μ meson. In two other *S* events, however, the ranges were between 65.6 and 67.7 g cm^{-2} and between 64.4 and 74.3 g cm^{-2} of lead. In still another case, the range was between 19 and 29 g cm^{-2} (an alternate possible interpretation of this event would be a catastrophic stopping of a π meson).

E.P. has measured the transverse momenta of the secondaries of charged *V* events observed in a cloud chamber.[2] These momenta lie between 54 ± 5 and 270 ± 63 Mev/*c*. In one case one could obtain the value, p^*, of the momentum of the secondary in the rest system of the primary particle; the value found was $p^*=120\pm30$ Mev/*c* assuming the secondary to be a

[1] Crussard, Leprince-Ringuet, Morellet, Orkin-Lecourtois, and Trembley. Compt. rend. **236**, 872 (1953); Phys. Rev. **90**, 1127 (1953).
[2] Fretter, Gregory, Johnston, Lagarrigue, Meyer, Muller, and Peyrou, Cosmic-Ray Conference, Bagneres, 1953 (unpublished).
[3] B. Rossi and H. S. Bridge, Cosmic-Ray Conference, Bagneres, 1953 (unpublished).
[4] R. Levi-Setti and G. Tomasini, Nuovo cimento **9**, 1244 (1952).
[5] H. S. Bridge and M. Annis, Phys. Rev. **82**, 445 (1951).
[6] Bridge, Peyrou, Rossi, and Safford, Phys. Rev. **90**, 921 (1953).

μ meson (or $p^*=116\pm30$ if the secondary is a π). This value, smaller than the largest measured values of transverse momenta, indicates clearly that secondaries of charged V events do not belong to a single monoenergetic group.

In the S events, the energy spectrum of the charged decay products appears to have a rather pronounced maximum at a momentum around 200 Mev/c.[3]

(6) M.I.T. found four S events in which the decay of a K meson gives rise to a photon of an apparent energy of the order of 100 to 200 Mev;[3,7] the direction of the photon is opposite to that of the charged decay product within the experimental uncertainty, which amounts to 5° in two cases and to 15° in the two other cases. However it is certain that photons with energies of the above magnitude are not associated with the decay of all K mesons.

The experimental results listed above are still sufficiently imprecise to allow several different interpretations. Here we only wish to point out that it appears possible to explain all K meson decays observed at E.P. and M.I.T. in terms of a single kind of particle with a single mode of decay. If one makes this assumption, one concludes from (1) that the mass of this particle must be between 900 and $1000m_e$; from (4) and (6) that μ mesons and photons are among the decay products; and from (5) and (6) that the decay is at least a 3-body process. We are then led to assume the following decay scheme:

$$K\rightarrow\mu+\gamma+\nu. \quad (1)$$

Moreover, one will notice that the mass of the K mesons discussed above is identical to that of the τ mesons, within the limits of the experimental uncertainty, and that there is no evidence for a difference in the mean lives of the two kinds of particles. It is thus possible that the two particles are actually identical, i.e., that there is one kind of K particle with two alternate decay schemes; i.e., (1) and

$$K\rightarrow3\pi. \quad (2)$$

Notice that, if we take for the K meson mass the well established value of the τ-meson mass ($970m_e$), we find a value of 236 Mev/c for the maximum momentum of the μ meson in the decay process (1).

One has still to explain the pronounced peak of the momentum spectrum of the μ mesons in the neighborhood of the maximum value. One has also to justify theoretically the fact that in rare cases a photon of fairly high energy is emitted in a direction nearly opposite to that of the μ meson, while in most cases the photon has a sufficiently small energy to escape detection.

The data summarized above include only results obtained at M.I.T. and E.P. If we consider also results obtained in other laboratories we find that our tentative interpretation meets the following objections:

(a) The Bristol group observed 3 or 4 cases in which the K meson secondaries appear to be π's of a single energy.[8] It has been assumed that in these cases the primary, designed by the letter χ, was a particle decaying into a π, and a single neutral particle.

(b) A small number of K meson secondaries, observed in emulsions, seem to have a momentum larger than 236 Mev/c (from scattering and ionization).[9]

(c) Daniel and Perkins measured the masses of 20 fast K particles emerging from stars. The mean of the mass values obtained by scattering and ionization is around $1200m_e$.[10]

(d) The studies on the nuclear absorption of negative K mesons made at Bombay (Peters)[11] and at Bristol (Friedlander)[12] seem to favor the assumption that the negative K mesons are of two different kinds and that only those representing the negative counterpart of τ mesons interact strongly with nuclei. If these preliminary observations should be confirmed, one could not maintain the assumption that τ mesons are identical to the K particles giving a single charged decay product. Moreover, there would be some difficulty in the assumption of the decay scheme (1) because, under this assumption, the K meson would have integer spin and should therefore interact strongly with nuclei if current views are correct.

Without minimizing the significance of the experimental results listed above, we feel that they need a further check before we can be sure that several different kinds of K mesons actually exist; and the main purpose of this note is to emphasize the importance of these checks. For the moment we only wish to point out that if all the available experimental data are taken at face value, even the assumption of three different kinds of K mesons (such as the τ, the χ, and the κ particle, according to the Bristol nomenclature) does not remove all difficulties of interpretation.

[7] Bridge, Courant, DeStaebler, and Rossi, Phys. Rev. **91**, 1024 (1953).

[8] M. G. K. Menon, thesis, Bristol, 1953 (unpublished). M. G. K. Menon and C. O'Cealleigh, Cosmic-Ray Conference, Bagneres, 1953 (unpublished).

[9] C. F. Powell, Cosmic-Ray Conference, Bagneres, 1953 (unpublished).

[10] R. R. Daniels and D. H. Perkins, Cosmic-Ray Conference, Bagneres, 1953 (unpublished).

[11] Lal, Pal, and Peters, Cosmic-Ray Conference, Bagneres, 1953 (unpublished).

[12] G. G. Harris and M. Friedlander, Cosmic-Ray Conference, Bagneres, 1953 (unpublished).