Observations on *S* Particles*

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SINCE March, 1954, the Princeton cloud-chamber group has been operating a dual cloud chamber similar to that of the Ecole Polytechnique.[1] The upper or magnet chamber has been described previously.[2] The lower or multiplate chamber has an illuminated region approximately 20 in.×20 in.×7 in. and the illuminated regions of both chambers are separated by 8 in. The material in the lower chamber has been in succession seven $\frac{1}{2}$-in. Pb plates and seven $\frac{1}{2}$-in. Cu plates. More recently, eleven tungsten plates each approximately 0.6 in. thick for a total of 290 g/cm² in the vertical direction have been installed. In this paper it is intended to describe those events in which either the primary or secondary of the *S* event[3] was observed in both chambers.

We have observed five *S* events whose primary masses were measurable by a momentum-range method. In one of these the secondary proceeded back into the upper chamber so that its momentum could be ascertained. In one other event the secondary stopped in the lower chamber. In all events the secondary traversed more than 30 g/cm² of copper, and no associated γ's were observed.

In a sixth event the primary was not observed in the upper chamber, but the secondary traveled back through the upper chamber for a distance of 30 cm. The measurements on this event are given in Table I.

To obtain the momentum of the secondary at the point of decay (p^*) one has to assume its mass and then use range-energy relations. Assuming the secondary is a μ meson and using the tables of Aron, Hoffman, and Williams,[4] we obtain $p^*=222\pm4$ Mev/c. Using the corrections to these tables described in the following Letter, we obtain 221 ± 4 Mev/c. On the assumed decay scheme $K_{\mu2}\rightarrow\mu+\nu$ the mass of the primary becomes $915\pm15m_e$ or $912\pm15m_e$, respectively. If, on the other hand, one assumes the secondary is a π meson and analyzes the event as a $\theta^+\rightarrow\pi^++\pi^0$ the secondary momentum becomes 235 ± 4 Mev/c when one uses reference 4, and 234 ± 4 Mev/c corrected, with the primary mass $1065\pm15m_e$ and $1062\pm15m_e$, respectively. This is inconsistent with the assumed decay scheme if the θ has a mass near that of the τ meson.[2,5]

In event number 244–96322, in which both primary and secondary are observed in the upper chamber, the secondary range and total momentum are not so well defined because it is impossible to determine whether or not the secondary traveled through a vertical counter wall of 8.5 g/cm² of Cu placed between the chambers. However, it appears in the upper chamber as a minimum ionizing track of momentum 117 ± 3 Mev/c after traversing a minimum of 51 g/cm² of Cu. The primary mass was measured as $(860_{-90}^{+70})m_e$ and it is therefore felt that this event is a well-established $K_{\mu2}$ heavy meson.

TABLE I. Measurements on secondary particle in event 161–48942.

Measured momentum in upper chamber	Range in material between chambers	Range in plates of lower chamber
147 ± 3.5 Mev/c	25.4 ± 1 g/cm² Cu	15.4 ± 1 g/cm² Cu

In event 242–94370 the secondary had a range of 63–83 g/cm² Cu. The masses of the five primaries when one uses reference 4 are (780 ± 90), (900 ± 80), (1080 ± 180), (935 ± 80), and $(860_{-90}^{+70})m_e$. The weighted mean of all five is $(891\pm40)m_e$, and for the two cases in which the secondary has a range greater than 50 g/cm² Cu it is $(905_{-80}^{+65})m_e$. When corrected for changes in the range-energy curves, these become $(900\pm40)m_e$ and $(914_{-80}^{+65})m_e$, respectively. These mass measurements coupled with the well-determined secondary of event 161–48942 are considered as confirming the evidence that the $K_{\mu2}$ has a mass lower than the τ meson, as indicated by the Paris group.[6]

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Masses of *S* Particles*

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MASS determinations of stopping *K*-mesons have been reported by several cloud-chamber groups.[1–3] Two methods are available when the so-called double cloud-chamber technique is used. (1) The mass of the *K*-meson is measured "directly" by a momentum range method. (2) The mass of the *K*-meson is determined by measuring the range of the charged decay product, assuming the nature of both the charged and neutral decay procucts, and treating the event as a two-body decay. This second method is available also when a single cloud chamber is used, containing plates of suitable stopping material.

During the past few years masses obtained by these two methods have appeared to differ systematically. Both methods require the use of the so-called range-energy curves, and all three groups referred to have used the results of Aron, Hoffman, and Williams.[4] The Paris group has pointed out that an error in the range-energy curves would affect the masses deduced by the two methods described above in opposite senses.

The recent work of several authors[5–8] indicates that for copper and lead, the stopping materials primarily used in the multiplate cloud-chamber experiments, a more suitable value of the mean excitation potential I would be $I=13.0Z$. In particular, the values of Bichsel and Mozley were: for Cu, $12.9Z$; and for Au, $13.1Z$ (corrected for K-shell electron effects, using protons of energy 6 to 18 Mev). When this new value of I is used, the range-energy curves shift in such a way that for a given mass and momentum, the range is increased by 1.6 percent. The several mass values available have been reconsidered on this basis.

The values of the Paris group[1] were as follows:

(a) $906\pm27m_e$ for an average of six events measured by method 1, where the secondary range was such as to require a μ meson, thus indicating a K_μ particle.

(b) $928\pm12m_e$ for an average of 22 events measured by method 1 not necessarily all K_μ's, thus indicating an upper limit to the K_μ mass.

(c) $941\pm11m_e$ determined by method 2 on the basis of nine events.

The value of the M.I.T. group for determination of the mass by method 2 was:

$948\pm15m_e$ based on the best two events of their sample. (This mass was obtained by taking the range reported,[2] using a μ mass of 105.8 Mev, and the curves of reference 4.)

The change in the range-energy curves reported above results in raising masses of method 1 and lowering those of method 2. The new results are then:

Paris:	906 is increased to $915\pm27m_e$,	(method 1)
	928 is increased to $936\pm12m_e$,	(method 1)
	941 is decreased to $934\pm11m_e$,	(method 2)
M.I.T.:	948 is decreased to $941\pm15m_e$.	(method 2)

The Princeton results[3] have been reported, taking into account the effect of the range-energy changes. These results were:

$900\pm40m_e$ for method 1 on the basis of five events,
$912\pm15m_e$ for the backward S.

This result is less sensitive to the range-energy changes than those masses obtained by method 2, due to the fact that a measurement of a residual momentum was possible.

At this time there seems to be no systematic difference between masses obtained by the two methods and no systematic difference among the results of the various groups. Also, it appears that the $K_{\mu2}$ mass is significantly less than the τ mass. It is also of interest to note that the mass of the $K_{\pi2}$ reported by the M.I.T. group[2] is changed from 952 to $946\pm12m_e$ by the change in the range-energy results.

Further improvement in the interpretation of the range-energy results is under consideration. This involves the use of more recent improved shell corrections for both the K- and L-shells in the analysis of the experimental stopping-power data and in the calculation of the range-energy relation.

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Gamma Stability of K-Mesons*

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ONE of the mysterious, and presumably significant, aspects of the heavy unstable particles is the remarkable clustering of masses in the neighborhood of $900–1000m_e$.[1] The reasonably well-established decay processes in this mass range are

$$\tau^\pm\rightarrow\pi^\pm+\pi^++\pi^-,$$
$$\theta^0\rightarrow\pi^++\pi^-,$$
$$\theta^\pm\rightarrow\pi^\pm+\pi^0,$$
$$K_{\mu2}{}^+\rightarrow\mu^++\nu,$$
$$K_{\mu3}{}^\pm\rightarrow\mu^\pm+2\text{ neutrals},$$
$$K_{e3}{}^\pm\rightarrow e^\pm+2\text{ neutrals}.$$

The best-known mass is that of the τ meson ($965.5\pm0.7m_e$)[2]; within the experimental errors this is identical with the mass of the θ^0 meson ($966\pm10m_e$).[3] The masses of the other particles are less well known, but there is some experimental indication that the $K_{\mu2}{}^+$ mass (estimated value $\sim940m_e$)[4] is distinctly below that of the τ meson. The estimated lifetimes for the various K-mesons lie in the range 10^{-10} to 10^{-8} sec.