EVIDENCE FOR THE CHARGED θ-MESON

By M. V. K. Appa Rao and S. Mitra
(*Tata Institute of Fundamental Research, Bombay* 1)

Received January 13, 1955
(Communicated by Dr. B. Peters, F.A.SC.)

Abstract

A K-meson is found to decay at rest into a nearly relativistic secondary particle. The secondary particle produces a nuclear disintegration in flight and is identified as a π-meson of kinetic energy ~ 110 MeV. The event is interpreted as the decay of a $\theta^{\pm}$-meson according to the scheme:

$$\theta^{\pm} \rightarrow \pi^{\pm} + \pi^{0} + (222 \pm 12 \text{ MeV.})$$

I. Introduction

Particles which come to rest by ionization and then emit a charged L-meson have been observed by many laboratories during the last two years. Heavy K-mesons as well as hyperons occur as parent particles and both π- and μ-mesons as daughter products. One particular type of particle, a charged K-meson decaying into one charged and one neutral π-meson:

$$\theta^{\pm} \rightarrow \pi^{\pm} + \pi^{0} \qquad (1)$$

has been suggested by Powell (Copenhagen Conference). Evidence has been accumulating in favour of the existence of this particle, but conclusive proof is still lacking.

In cloud chambers, there are several events in which a particle comes to rest and emits a secondary whose range is close to 60 gm./cm.^{2} of lead (corresponding to the expected energy of $\pi^{\pm}$-meson from $\theta^{\pm}$ decay); sometimes a soft cascade accompanies the decay. But in none of these cases could the primary or the secondary particle, through mass measurements, be directly identified as K-meson and π-meson respectively.

In nuclear emulsions many events have been reported in which the primary is identified as a K-meson and the secondary as a L-meson. In some cases the L-meson seems to carry about 50% of the available energy suggesting a two-body decay. The neutral π-meson assumed to be emitted by the $\theta^{\pm}$-meson is not observable at present except through pair production induced by the γ-rays into which it decays. In nuclear emulsions, the electron-positron pairs are observable, but since they are usually separated from the decay point by a distance of several centimetres, it will only in rare cases be possible to associate a given electron-positron pair with the decay of a heavy particle. Nevertheless, the identification of the charged θ-meson in emulsions is possible, provided the charged decay product can be definitely identified as a π-meson and provided it can be shown that its total energy E_π and the mass of the parent particle are connected by the relation appropriate to decay scheme (1) namely:

$$M_{\theta^\pm} = E_{\pi^\pm} + (E^2_{\pi^\pm} + m^2_{\pi^0} - m^2_{\pi^\pm})^{\frac{1}{2}} \qquad (2)$$

Several such cases in emulsions have been reported. In each case the secondary meson is, however, identified as a π-meson only by measurement of ionization and scattering, which is never quite conclusive. In the event reported here the secondary is observed to interact with a nucleus and, therefore, can definitely be identified as a π-meson.

Since there is not yet conclusive evidence for the charged θ-meson which decays into two π-mesons, it still seems worthwhile to report individual cases which are easiest interpreted by such a decay scheme.

II. Description of the Event

A K-meson (K-15) is ejected from a star of type $16 + 0\,n$ and comes to rest after traversing 4·98 mm. in two emulsions. A fast charged particle is emitted from the point at which the K-meson comes to rest. The track of the secondary particle is very flat and has a potential range of $\sim$10 cm. in the stack (size of the stack $15 \times 15 \times 12$ cm.^{3}).[1] However, after traversing a distance of 4·05 cm. in two emulsions it produces a nuclear disintegration of type $5 + 0\,p$.

III. Measurements

1. *Primary Particle.*—The scattering measurements on the primary particle track were made by the constant Sagitta method.[2] We obtain a mass

$$M = 937 \begin{array}{l} + 250 \\ - 170 \end{array} m_e$$

2. *Secondary Particle.*—Measurements of scattering and grain density were made on the secondary particle track.

(*a*) *Scattering Measurements.*—The region of the plate in which the decay occurs is distorted due to the formation of a bubble during processing. Hence we restricted our scattering measurements to the second plate. Using a constant cell length of 50μ, second and third differences (d_2 and d_3) were evaluated for 50μ, 100μ and 150μ cells. The values for d_2 were calculated by eliminating noise with higher cell sizes and also by removing constant noise. The mean α_{100} was calculated and $p\beta$ was obtained. The results are given in Table I.

(*b*) *Grain Density Measurements.*—Grain density on the secondary particle track was measured in both the emulsions traversed by it. Elaborate grain density measurements were made on flat electron-positron pairs in the same plate to obtain the plateau value of grain density for the plate. Measurements of grain density on electron-positron pairs were restricted to the same depth from the emulsion surface as that of the secondary track.

The value for $p\beta$ obtained from scattering measurements and the g/g_{pl} obtained for the grain density show that the secondary particle must be an L-meson. Since the secondary particle produces a disintegration, it is a π-meson. Using the known π-meson mass we have determined the kinetic energy of the π-meson using our empirical range *versus* grain density calibration curve, and the semi-empirical range-energy relation suggested by Daniel, George and Peters.[3] The results are given in Table I.

However, when the grain densities are close to minimum the calibration curves are not reliable. Therefore, we have calculated the kinetic energy of the π-meson also from the theoretical relation between specific energy loss and particle energy, as given by J. Smith.[4] Assuming that in the region of interest here, where the grain density is close to its minimum value, it is proportional to specific energy loss, we have

$$\frac{\left(\frac{dE}{dX}\right)}{\left(\frac{dE}{dX}\right)_{min.}} = \frac{g}{g_{pl}} \times \frac{g_{pl}}{g_{min.}}$$

where g_{pl} and $g_{min.}$ are the grain densities at plateau and at minimum respectively. The value for $g_{pl}/g_{min.}$ according to Stiller and Shapiro[5] and Fleming and Lord[6] is $1 \cdot 14 \pm \cdot 03$. Using our measured value of g/g_{pl} we calculated $(dE/dX)/(dE/dX)_{min.}$ from the above formula and obtained the corresponding π-meson energy with the help of table given by Smith.

TABLE I

Type of measurement	Plate in which measurement was made	Mean distance from the decay point	$p\beta$	g/g_{pl}	Total estimated range of π-meson		Kinetic energy of π-meson	
Scattering	Second	3·29 cm.	144^{+16}_{-14}	..	$11{\cdot}34^{+1{\cdot}55}_{-1{\cdot}25}$ cm.		$112{\cdot}3^{+10{\cdot}2}_{-8{\cdot}2}$ MeV.	
Grain density	First	0·398 cm.	..	1·138 ± ·032	$6{\cdot}35^{+{\cdot}55}_{-{\cdot}50}$ cm.		$76{\cdot}1^{+4{\cdot}4}_{-4{\cdot}0}$ MeV.	
					(i) Using our empirical grain density *versus* range curve	(ii) Using the theoretical relation between particle energy and specific energy loss	From (i)	From (ii)
Grain density	Second	3·265 cm.	..	1·078 ± ·033	$10{\cdot}5^{+1{\cdot}3}_{-1{\cdot}3}$ cm.	$11{\cdot}5^{+2{\cdot}5}_{-1{\cdot}6}$ cm.	$106{\cdot}7^{+8{\cdot}7}_{-8{\cdot}7}$ MeV.	$113{\cdot}2^{+16{\cdot}3}_{-10{\cdot}5}$ MeV.

The indicated errors in the energy of the π-meson obtained from grain density are standard deviations due to the finite number of grains counted and the probable error due to uncertainty in the grain density *versus* range curve. Possible errors in the range energy curve have not been taken into account.

We have no explanation for the high g/g_{pl} value obtained in the first plate except that a bubble at a distance of about 2 mm. from the event introduced some inhomogeneities in development. In the second plate, we have no such disturbance and since here the values of true range of the π-meson as obtained from the grain density and scattering measurements are consistent with each other, we shall accept them as reliable and are forced to reject the grain density measurements in the first plate.

In order to be consistent with all remaining determinations within one standard deviation the π-meson energy should lie between the limits $104 \cdot 1 < W_\pi < 115 \cdot 4$ MeV.

IV. INTERPRETATION

Since no charged particle other than one π-meson is associated with the rest-point of the K-meson, we interpret the event as due to the decay of a K-meson into a single charged secondary and one or more neutral particles, rather than the capture of negative K-meson. The energy of the π-meson exceeds 100 MeV. and is, therefore, much too high to permit the interpretation $\tau^\pm \rightarrow \pi^\pm + 2\pi^0$. Other three-body decay schemes with less massive neutral particles cannot, however, be ruled out. If interpreted as a two-body decay we have the following results:—

$$\theta^\pm \rightarrow \pi^\pm + \pi^0 \qquad M_\theta^\pm = 971 \pm 22 m_e$$

$$K^\pm \rightarrow \pi^\pm + \gamma \qquad M_K = 892 \pm 24\, m_e$$

Both mass values are consistent with that obtained from direct measurements. The mass obtained from the first scheme agrees also with the mass of the neutral θ-meson ($M_\theta{}^0 = 965 \pm 10\, m_e$)[7] which decays into two-charged π-mesons.

Thus while the event discussed here does not constitute a complete proof for the existence of charged θ-mesons, the agreement between measured quantities is closest on the assumption that the charged θ-meson exists and decays according to the scheme:

$$\theta^\pm \rightarrow \pi^\pm + \pi^0 + (222 \pm 12 \text{ MeV.})$$

ACKNOWLEDGEMENT

We are grateful to Professor B. Peters for his keen interest and guidance throughout the preparation of this paper. Our thanks are due to Dr. R. R. Daniel for his active help during our work and to Mr. D. Lal for helpful discussions.

REFERENCES

1. Daniel, R. R., Friedmann, G. B., Lal, D., Yash Pal and Peters, B. — *Proc. Ind. Acad. Sci.*, 1954, **40**, 151.
2. Biswas, S., George, E. C. and Peters, B. — *Ibid.*, 1953, **38 A**, 418.
3. Daniel, R. R., George, E. C. and Peters, B. — *Ibid.* (In press).
4. Smith, J. .. *Phys. Rev.*, 1947, **71**, 32.
5. Stiller, B. and Shapiro, M. M. .. *Rochester Conference Report*, 1952.
6. Fleming, J. R. and Lord, J. J. .. *Phys. Rev.*, 1953, **92**, 511.
7. Thompson, R. W., Burnwell, J. R., Cohn, H. O., Huggett, R. W. and Karzmark, C. J. — *Ibid.*, 1954, **95**, 661.