Properties of Heavy Unstable Particles

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A block of emulsion consisting of unbacked emulsion sheets can be used as a very efficient detector for heavy unstable particles and provide favorable conditions for mass and energy determinations. The mass of the τ meson was obtained as $m_\tau=3m_\pi+Q$, where $Q=76.0\pm0.9$ Mev. Fairly accurate mass values are obtained for the positive K meson and four examples of the capture of negative heavy mesons are presented, two of them leading to emission of a π meson. A charged particle of mass higher than that of a proton which decays in flight into a meson is discussed. In most of these cases the nuclear event giving rise to the heavy mesons could be observed. The Q value of the V_1^0 particle was determined as 37 ∓ 2 Mev and other examples which may represent the decay of neutral particles are discussed.

IN this paper we give the result of measurements on 12 heavy charged unstable particles of which 10 are observed to be ejected from nuclear events. The particles are identified as

3 τ mesons,
4 K mesons (probably positive),
4 K mesons (negative),
1 $V^\pm$ particle decaying in flight.

We also give results on 4 events which probably represent the decay of neutral heavy particles. These particles are tentatively identified as

1 V_2^0 particle,
2 V_1^0 particles,
1 particle of mass $\sim4100\ m_e$.

All the events were observed in a solid block of emulsions consisting of 24 emulsion sheets 6 in.×4 in. and 600μ thick exposed in the stratosphere at geomagnetic latitude 19°. After exposure these emulsion sheets were mounted on glass plates and carefully aligned on slides such that particle tracks could be traced through the entire block. With such an emulsion arrangement it is comparatively easy to identify various types of particles and trace them to their origin. (The track length available for measurement is frequently of the order of several cm.)

τ MESONS

Three examples of τ mesons were found. One is emitted with an energy of 31.7 Mev from a star which according to the nomenclature of Brown *et al.*[1] is designated by $6+0p$. The decay products consist of one positive π meson of 22.4 Mev and one negative π meson of 15.4 Mev which come to rest in the emulsion block, as well as one meson which escapes.

The second τ meson is produced with 6.4-Mev energy in a star of the type $21+2\alpha$. Of the decay products two positive π mesons (of 25.8 and 16.2 Mev, respectively) come to rest in the block; the third escapes after traversing five emulsion sheets.

The third τ meson is emitted with 33.6 Mev from a star of the type $13+10\alpha$. In this case only one of the 3 decay products comes to rest in the block (a positive π meson of 6.63-Mev energy). Details on these three particles are given in Table I. In each case the Q values and masses quoted are those obtained by using the energy of the two decay products which can be determined with the greatest accuracy and calculating the energy of the third decay product from conservation of momentum assuming that all decay products are π mesons. Combining the results of these observations, we obtain as our best value for the mass of the τ meson

$$M_\tau=969.3\pm1.7\ m_e,\quad Q_\tau=72.2\pm0.8\ \text{Mev}.^2$$

TABLE I. τ mesons.

No.	Origin	Parent particle Range (cm)	Parent particle Energy (Mev)	Q value (Mev)	Mass	Decay products Range (cm) observed (o) or total (t)	Decay products Energy (Mev)	Angles of emission
1	$6+0p$	0.6650	31.7	72.2 ± 1.5	969.0 ± 3	(a) 0.898 (t)	22.4	$\measuredangle ab=93°$
						(b) 0.478 (t)	15.4	$\measuredangle bc=131°$
						(c) 0.37 (o)	34.4	$\measuredangle ca=136°$
2	$21+2\alpha$	0.0367	6.4	72.8 ± 1.5	970.8 ± 3	(a) 1.1474 (t)	25.8	$\measuredangle ab=105°$
						(b) 0.5369 (t)	16.2	$\measuredangle bc=118°$
						(c) 0.46 (o)	30.8	$\measuredangle ca=137°$
3	$13+10\alpha$	0.7468	33.6	71.7 ± 2.0	968.3 ± 4	(a) 0.1135 (t)	6.63	$\measuredangle ab=78°$
						(b) 0.45 (o)	29.8	$\measuredangle bc=168°$
						(c) 1.2161 (o)	35.3	$\measuredangle ca=116°$

[1] R. H. Brown *et al.*, Phil. Mag. **40**, 862 (1949).
[2] *Note added in proof.*—These values were obtained before correcting for variations in individual emulsion thicknesses and for the effect of distortion on the angles between steep tracks. More refined measurements are described in the Proc. Indian Acad. Sci. (to be published) and yield $Q_\tau=76.0\pm0.9$ Mev and $M_\tau=996.8\pm1.8m_e$.

TABLE II. Positive K mesons.

No.	Origin	Range (cm)	No. of emulsions traversed	Mass values (m_e) g/R	Sc/R	M.R.	Energy of secondary
1	$20+5n$	1.36	1	1090 ± 100	990 ± 120	1130 ± 130	$p\beta=226\pm20$ Mev/c
2	$14+2n$	1.2	1	1080 ± 100	940 ± 150	1140 ± 150	$g/g_{pl}=0.98\pm0.12$
3	Outside of block	5.20	14	1220 ± 100	1010 ± 100	920 ± 100	$g/g_{pl}\approx1$
4	$1+0n$	3.15	5	1070 ± 100	1010 ± 110	1050 ± 100	$g/g_{pl}=0.93\pm0.07$

Of the three τ mesons, two were discovered by tracing back towards their origin, the tracks of positive and negative π mesons which stopped in the emulsion. From the observed yield we estimate the ratio of slow (presumably positive) τ mesons to slow π mesons produced at this latitude and altitude as

$$\tau^+/\pi^\pm=1.0\pm0.7 \text{ percent.}$$

The same $13+10\alpha$ star which gives rise to the third τ meson also contains a $V^\pm$ *particle*. This particle has an observed range of 1.93 cm and decays just before it comes to rest. Its residual range at the point of decay is $0.35^{+0.25}_{-0.15}$ cm. The mass of the particle is 2520 ± 400 m_e. The decay product can be observed over a track length of 1.4 cm; its mass is 330 ± 60 m_e and $p\beta=160\pm13$ Mev/c. Thus, 1.9×10^{-10} sec after its creation, the V particle decayed into a (presumably) π meson of energy 103 ± 9 Mev. If together with the π meson a single neutral particle is emitted, its mass must be larger than 1570 m_e. The observed event is consistent with the decay scheme: $V^\pm\rightarrow\pi^\pm+\text{neutron}+Q$. If this scheme is assumed the mass of the V particle is $M=2330\pm30$ m_e and the Q value is $Q=135\pm35$ Mev.

POSITIVE K MESONS

Table II gives the measurements on four particles which come to rest in the emulsion before they decay; they seem to form a homogeneous group. The mass values in the fifth column are obtained from measurements of grain density *vs* particle range (g/R); the mass values in the sixth column are obtained from measurements of scattering *vs* range (Sc/R) by using a method of varying cell length which accurately takes into account the energy loss along the trajectory. (This method, which will be described elsewhere, is, we believe, capable of great accuracy.) The mass values in the seventh column are obtained from scattering *vs* range using the method described by Menon and Rochat (M.R.).[3] The last column gives the $p\beta$ value or the grain density (in terms of its plateau value) of the decay products.

The best mass value from scattering measurements for the 4 positive K mesons is

$$M_{K^+}=1025\pm50\ m_e.$$

Here the error given is the standard deviation based on statistical fluctuations only. An additional systematic error of the order of 50 m_e cannot be ruled out

TABLE III. Negative K mesons.

No.	Origin	Range	Mass (m_e)	Range total (t) or observed (o)	Visible prongs in capture star: Mass (m_e)	Energy (Mev)	Remarks
1	$14+2n$	308μ	1000^{+720}_{-400}	15.8μ (t)			Probably proton.
				5.7μ (t)			Probably proton.
				0.39 cm (o)	300^{+70}_{-40}	24.7 ± 0.8	π meson.
2	$25+5n$	92μ	?	48μ (t)			Probably proton.
				5.5μ (t)			Probably proton.
				139μ (t)			Scatters very strongly.
				0.354 cm (o)	210^{+50}_{-40}	25.3 ± 1.0	This particle is a π meson since it produces a nuclear interaction in flight after traversing 3.5 mm of path.
3	$4+6n$	2.5 cm	1010 ± 150	385μ (t)			Probably proton.
				46μ (t)			Probably proton.
				140μ (t)			Probably proton.
				0.14 cm (o)		>20 Mev	Proton or deuteron.
				1.76 cm (o)	1836	>175 Mev	Proton.
4	Outside of block	2.926 cm	840 ± 200	407μ (t)			Probably proton.
				456μ (t)			Probably proton.

[3] M. G. K. Menon and O. Rochat, Phil. Mag. 42, 1232 (1951).

TABLE IV. V_1^0 particles.

Angle between tracks	Decay products: Range (cm) Observed (o) or total (t)	Mass (m_e)	Energy (Mev)	Parent particles: Q Mev	Mass (m_e)
169° 48′	0.0725 (t) 1.85 (o)	276 1850±180	5.22 π^- 118±7 (p)	37±2	2184±4
168° 36′	0.5284 (t) 0.60 (o)	276 ∼1800	16.5 π^- 42±3 (p)	38±3	2186±6
131°	0.80 (o) 0.917 (t)	240±40 3970^{+900}_{-600}	49.5±3.5 (π^-) 67.5 (d)	89±10	4120±20

until more calibration measurements have been carried out with our new scattering procedure. It is, therefore, not possible at this moment to state definitely whether or not the mass of these particles is different from that of the τ meson.

It is interesting to note that the last particle in Table II does not originate in a star but is produced by itself in the middle of the emulsion. There is, however, a very steep minimum ionization track which seems to cross the K-particle track about 3μ from its origin. Although we do not believe that the two tracks are associated, it is possible that the origin of this particle should be described as of the type $1+1p$ or $1+2n$.

NEGATIVE K MESONS

Table III contains data on four K mesons captured by nuclei at the end of their range. The first one originates in the same star as the positive K particle No. 2 listed in Table II.

Particles No. 1 and No. 2 give very similar capture stars, both giving a π meson of $\sim$25 Mev and some unusually short black tracks.

Particle No. 3 suffers a 8° deflection 6 mm before the end of its range. There is some indication that the mass after this deflection is reduced ($680\pm150\ m_e$), but the evidence is not conclusive. The energy of the visible prongs emitted at capture put a lower limit of 480 m_e on the mass of the particle after deflection.

Based on the fraction of capture stars investigated which led to the discovery of K^- mesons, we estimate the ratio of slow π^- to slow K^- mesons produced at this altitude and latitude as $K^-/\pi^-=(3\pm1.8)$ percent.

V_2^0 PARTICLE

A positive π meson of 11-Mev energy is emitted from a two-prong star and comes to rest in the emulsion block. The second track which makes an angle of 69° with the π^+ track can be observed over a distance of 1.2 cm. Grain density ($g/g_{pl}=0.9\pm0.04$) and scattering measurements ($\alpha_{100}=0.056\pm0.008$) show that the particles' mass is less than 30 percent of the proton mass and that it has a momentum $p\beta=450\pm70$ Mev/c. Assuming a two-body decay scheme $V_2^0\rightarrow\pi^++\pi^-$, we obtain

$$M(V_2^0)=810\pm35\ m_e,\quad Q(V_2^0)=132\pm17\ \text{Mev}.$$

V_1^0 PARTICLES

A group of 85 π mesons (34 π^+ and 51 π^-) whose tracks were traced from their point of decay or capture to their point of origin in the emulsion block can be classed according to their mode of production in the following way:

$^+\pi$	π^-	Total	
2	—	2	came from τ mesons.
1	—	1	came from the V_2^0 particle mentioned above.
30	43	73	came from stars with more than 2 prongs.
1	8	9	came from "two-prong stars."
34	51	85	

Some of the last mentioned 9 cases are undoubtedly genuine nuclear events; in one case a recoil is visible at the origin of the meson, and in two other cases a slow electron is emitted. There are also 3 cases where it cannot safely be ruled out that a δ ray in the neighborhood is associated with the production of the meson. These dubious cases will be discussed elsewhere. In 3 cases, however, there can be no doubt that only two charged particles originate at a point. They probably represent the decay of a neutral unstable particle, and in Table IV they have been analyzed on the assumption that they represent two-body decays. The Q values in the first two cases are in close agreement with those obtained in the analysis of V_1^0 particles observed in cloud chambers. The third case, if interpreted correctly, represents the decay of a particle which has not previously been observed.

Full details on the measurements reported in this paper will be published shortly in the *Proceedings of the Indian Academy of Sciences*. The technical details involved in preparing an accurately aligned solid block of emulsions as well as the new method of obtaining particle masses from range and scattering measurements with variable cell lengths will also be published shortly in the same journal.

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