ANALYSIS OF τ-MESONS

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ABSTRACT

We describe in this paper measurements made on the decay products of 11 τ-mesons observed in large nuclear emulsion block detectors. Out of the 33 charged decay products, 27 have been arrested in the block, and were identified as π-mesons. The charge of the τ-meson was found to be positive in 6 cases. In one case the charge of the τ-meson is possibly negative and in 4 cases it could not be determined. Omitting one τ-meson in which a high energy γ-ray is emitted and which has been reported earlier[1] the weighted mean Q-value of the remaining 10 τ-mesons is:

$$Q_\tau = 76 \cdot 3 \pm 0 \cdot 3 \text{ MeV}$$

which gives the mass of the τ-meson as:

$$m_\tau = 968 \cdot 7 \pm 0 \cdot 6\, m_e$$

This value is slightly higher than the mean value $965 \cdot 5 \pm 0 \cdot 7\, m_e$ compiled by Amaldi *et al.*[2] from measurements of various laboratories.

We have so far observed 11 cases of disintegration of τ-mesons at rest into charged π-mesons. These events occurred in three emulsion block detectors whose construction has been described elsewhere.[3, 4] Of these 11 τ-mesons, 7 were found by tracing π-mesons from the end of their range back towards their origin; the remaining 4 τ-mesons were discovered during systematic scanning. Ten of the 11 τ-mesons could be traced back to the nuclear explosion in which they originated.

Of the 33 charged decay products, 27 came to rest in the emulsion blocks, and were identified as π-mesons ($18\pi^+$, $8\pi^-$, and 1 more π-meson with a probably negative charge). The charge of the τ-meson was positive in 6 cases. In 1 case (τ_9) observational conditions at the end of one of the π-meson tracks are unfavourable. The π-meson becomes suddenly very steep near the end of its range and stops after travelling another $712\,\mu$ in the emulsion. We have not been able to detect any decay electron at the point where the particle stopped nor any point where change of direction or of grain density suggests that the π-meson decayed into a μ-meson. Hence this π-meson might be negative. If this interpretation is accepted τ_9 gives rise to two negative and one positive π-meson.

Table I gives the results of measurements on all 11 events. τ_1, τ_2 and τ_3 have already been reported.[5] Their Q-values given in Table I are slightly different from those reported earlier, because we have based all our analyses on a slightly modified range energy relation.[6]

τ_4 is abnormal since nearly 50% of the available kinetic energy is carried away by a γ-ray and not by the three π-mesons. This event has been discussed in detail in an earlier paper by Daniel and Yash Pal.[1] τ_5 and τ_8 suffer inelastic collisions before they come to rest. These collisions have been discussed in a previous paper by Daniel and Lal,[7] but the data on the decay products of these τ-mesons have not been published before.

The first four columns in Table I give information on the parent particle. The τ-meson number is given in column 1, column 2 gives the description of the nuclear event in which the τ-meson originates (we use here the nomenclature of Brown *et al.*[8]). The range of the τ-meson before it comes to rest and the energy of the τ-meson at emission are given in columns 3 and 4 respectively.

The next 4 columns of Table I give information on the decay products. The charge of the π-meson is given in column 5 when it can be inferred from its behaviour at rest ($\mu - e$ decay or capture star). When the charge of the π-meson is unknown a question mark is inserted.

The range of the π-mesons is given in column 6. All range measurements were carried out independently by two observers. The symbol (t) in column 6 signifies that the particle comes to rest in the block and its total range has been measured. The symbol (o) indicates that the particle escapes and only the observed portion of the range is given.

The energy of the π-meson is listed in column 7. The range-energy curve which we used[6] is based on a flat μ-meson range of $574 \cdot 5 \pm 7 \cdot 7\,\mu$ while in our detector the mean range of flat μ-mesons obtained from the decay of π-mesons at rest is $(579 \cdot 9 \pm 3 \cdot 6)\,\mu$. Hence we have reduced the observed ranges by the ratio 574·5/579·9, before using the range-energy relation.

The angle between the tracks is given in column 8. The Q-values and their estimated errors are obtained as follows: If all the three π-mesons come to rest in the block, the Q-value was obtained by merely adding the

TABLE I

Parent Particle				Secondary Particles				
1 No.	2 Origin	3 Range (cm.)	4 Energy (MeV)	5 Sign of charge	6 Range in μ	7 Energy (MeV)	8 True angles (degrees)	9 Q-value (MeV)
1	21+ 2 α	·0367	6·4	1 + 2 + 3 (—)	5262 (t) 11245 (t) 4600 (o)	16·77 26·12 (33·40 ± ·70)	α = ∢2·3 = 137·20 β = ∢3·1 = 121·85 γ = ∢1·2 = 100·80	76·24 ±1·03
2	6+ 0p	·665	31·7	— + ?	4638 (t) 8636 (t) 3364 (o)	15·45 22·29 (38·20 ±1·00)	α = 141·60 β = 132·90 γ = 85·50	75·46 ±1·69
3	13+10 α	·747	33·6	+ ? ?	1115 (t) 3000 (0) 11820 (o)	6·85 (29·98 ±1·08) 39·05	α = 161·80 β = 118·80 γ = 79·30	75·88 ±2·59
4	9+ 1 n 0p	8·700	145·9	+ + (—) γ-ray	124 (t) 3921 (t) 2500 (o)	1·85 13·60 (30·6 ± 2·2) 32·10	α = 128·85 β = 56·00° γ = 146·80	78·2 ±4·9
5*	8+10p	1·315	47·0	— ? +	1050 (t) 13792 (t) 24294 (t)	6·49 29·02 40·52	α = 158·74 β = 127·25 γ = 74·01	76·03 ± ·88
6	26+ 2p	4·100	88·6	+ — +	5294 (t) 12103 (t) 16861 (t)	16·90 27·07 32·84	α = 136·95 β = 118·40 γ = 104·61	76·81 ± ·82
7	22+ 5p	2·200	62·19	+ + —	3288 (t) 5862 (t) 30777 (t)	12·62 17·88 46·50	α = 159·70 β = 154·90 γ = 45·60	77·00 ± ·90
8*	8+ 1p	1·150	44·0	+ + —	323 (t) 16380 (t) 22490 (t)	3·35 32·14 38·71	α = 166·15 β = 122·63 γ = 71·15	74·20 ± ·88
9	12+ 6p	·970	38·71	— — —(?)	2140 (t) 13583 (t) 21650 (t)	9·69 28·64 38·28	α = 153·20 β = 123·85 γ = 82·95	76·61 ± ·86
10	The Primary could not be followed completely			— ?	2951 (t) 6508 (o) 24522 (t)	11·60 (25·21 ± ·13) 40·71	α = 150·00 β = 130·95 γ = 79·00	77·52 ± ·87
11	25+11 n	7·600	125·82	[illegible]	1108 (t) 12897 (t) 25671 (t)	6·72 27·94 41·78	α = 159·45 β = 120·90 γ = [illegible]	76·44 ± [illegible]

energies of the three π-mesons. The indicated error on the Q-value contains only the effect due to straggling. We have calculated the effect of straggling on the basis of the formula given by Symon.[9] But we have increased the theoretical values by 20% which seems to be required to obtain agreement between Symon's calculations and the experimental straggling value of Fry and White.[10]

If one of the mesons escapes, Q-values are calculated from the remaining 5 observables (2 momenta and the 3 angles). By choosing 1 of the momenta and any 2 of the remaining observables, one obtains 5 different Q-values. The Q-values given in Table I represent the average of these 5 determinations and the error given is the maximum deviation of any of these 5 values from the average.

The most serious uncertainty arises from variations in the thickness of individual emulsion sheets. The method by which we have tried to minimise this effect is given in the Appendix.

Conclusions

Omitting the 4 body decay τ_4, the weighted average Q-value was obtained by choosing weight factors inversely proportional to the square of the error attached to each value. Our best Q-value is:

$$Q_\tau = 76{\cdot}3 \pm 0{\cdot}3 \text{ MeV}$$

and

$$m_\tau = 968{\cdot}7 \pm 0{\cdot}6\, m_e{}^*$$

This value is about 1·6 MeV higher than the value obtained by Amaldi[2] on the basis of data reported by many laboratories at the Padova Conference on Elementary Particles in 1954.

Figure 1 shows the distribution of our values together with those from other laboratories.

Omitting the abnormal τ_4 we have computed the ratio $E\pi^-/Q_\tau$ for those cases in which the charge of the τ-meson is known to be positive and in which the negative π-meson has been identified. The mean value

$$\left\langle \frac{E\pi^-}{Q\tau} \right\rangle = 0{\cdot}3360 \pm 0{\cdot}0026$$

indicates complete symmetry in the energy distribution among the decay products.

* m_τ is calculated from the relation $m_\tau = 2m_{\pi^+} + m_{\pi^-} + Q$, where m_{π^+} and m_{π^-} are those given by Smith, Birnbaum and Barkas.[11]

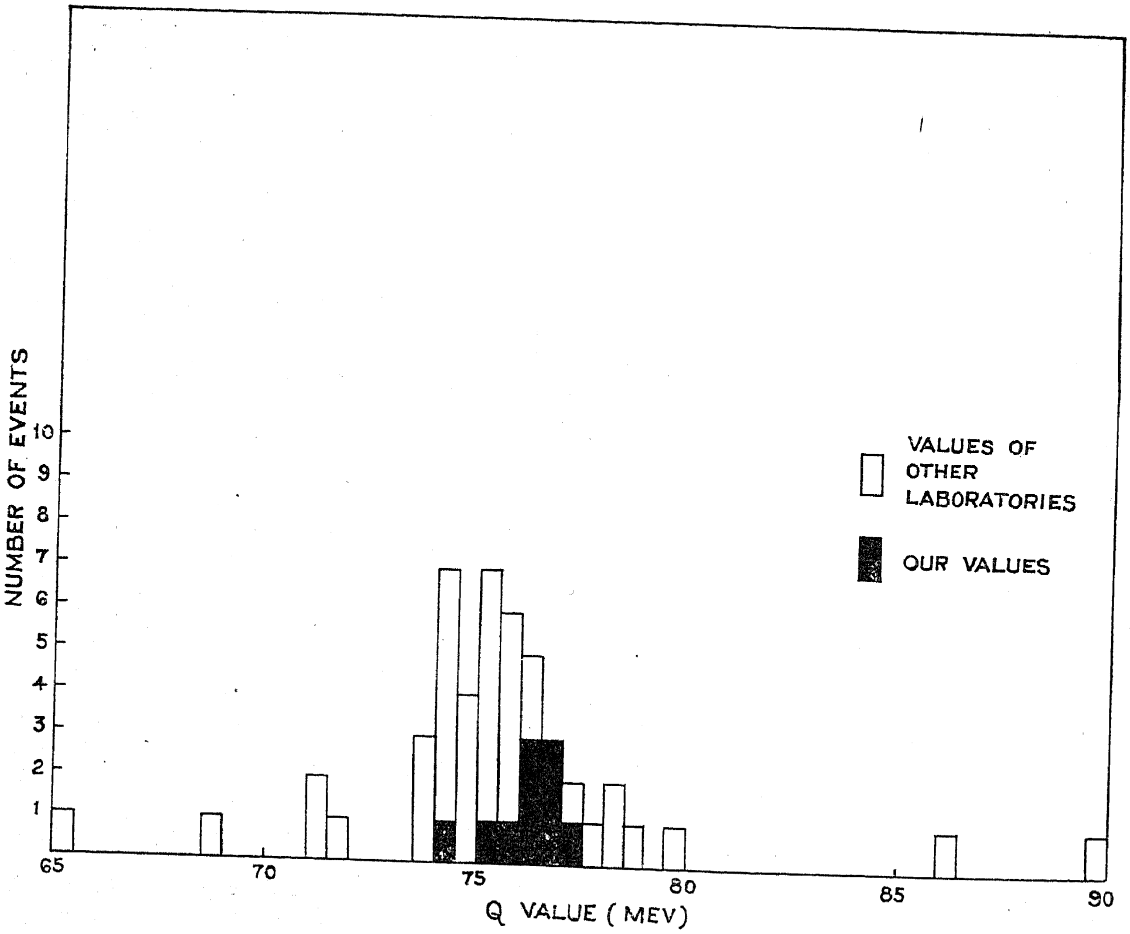

FIG. 1

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APPENDIX

An accurate determination of the range of particles and hence their energy, requires a knowledge of the emulsion thickness before processing. A private communication from Ilford Limited states that variations as high as 10% can occur in the thickness, between different parts of the same emulsion sheet, as well as between different emulsion sheets although usually variations are much lower. In the construction of two big emulsion blocks, we have used five different batches of emulsion sheets manufactured on different dates. Each batch consisted on the average from 50–100 sheets. Their mean thickness was determined as follows:—

We measured the range of 50 flat μ-mesons emitted from π-mesons at rest and of 14 steep μ-mesons which occur in a single batch of emulsions. The average range of the steep μ-mesons depends on the assumed emulsion thickness d. We chose for the average emulsion thickness in the batch that value of d which makes the mean range of flat and steep μ-mesons identical.

The relative mean emulsion thickness in different batches was obtained by determining separately the mean projected length of heavy primary nuclei which traversed plates belonging to different batches. In this way we found that our emulsion blocks were composed of emulsions belonging to 5 different manufacturing batches with mean thickness of 600 μ, 637 μ, 650 μ, 660 μ and 667 μ respectively.

REFERENCES

1. R. R. Daniel and Yash Pal, *Proc. Ind. Acad. Sci.*, 1954, **40** (3), 114.
2. E. Amaldi, E. Fabri, T. F. Hoang, W. O. Lock, L. Scarsi, B. Touschek and B. Vitale *Nuo. Cim.*, 1954, **12**, (9), *Supple.* 2, 419.
3. D. Lal, Yash Pal and B. Peters *Proc. Ind. Acad. Sci.*, 1953, **38** (4), 277.
4. R. R. Daniel, G. Friedmann, D. Lal, Yash Pal and and B. Peters *Ibid.*, 1954, **40** (4), 151.
5. D. Lal, Yash Pal and B. Peters *Ibid.*, 1953, **38** (5), 398.
6. R. R. Daniel, E. C. George and B. Peters *Ibid.*, 1955, **41** (2), 45.
7. ——— and D. Lal .. *Ibid.*, 1955, **41** (1), 15.
8. R. H. Brown, U. Camerini, P. H. Fowler, H. Heitler, D. T. King and C. F. Powell *Phil. Mag.*, 1949, **40**, 862.
9. K. R. Symon .. Harvard University *Thesis* (1948); Quoted in: *High Energy Particles* by B. Rossi, Prentice Hall, Inc., New York, 1952, pp. 37.
10. W. F. Fry and C. R. White *Phys. Rev.*, 1953, **90**, 207.
11. F. M. Smith, W. Birnbaum and W. H. Barkas *Ibid.*, 1953, **91**, 765.