Four τ-Mesons Observed on Kilimanjaro

By K. R. Dixit

The Institute of Science, Mayo Road, Bombay I, India

(Z. Naturforschg. **9a**, 355—357 [1954]; eingegangen am 18. März 1954)

Four τ-meson-events observed on the top of mount Kilimanjaro are described. Two of them definitely show that a τ-meson can disintegrate into two π-mesons and one μ-meson. The third event also indicates the same possibility, whereas no definite conclusion whatever can be drawn from the fourth event. The mean mass of the τ-meson comes out as 959 ± 10 electron masses.

Three stacks of Ilford G 5 nuclear emulsions were exposed to the cosmic rays for 30 days (during August-September 1953) on the top of mount Kilimanjaro-Gilman's Point (37. 20 E, 3.05 S and altitude 5964 M). In one stack the plates were all horizontal and 400 μ thick, in the second stack all plates were inclined and 200 μ thick, while in the third stack the plates were all vertical and only 100 μ thick. The 100 μ plates are comparatively easy to scan and we have so far scanned about 3 ccm of emulsion. We began by routine scanning, but when we observed a τ-meson (event 4) we began to look for the τ-mesons in addition. This was done in the following way. Any time we came across a threefold cosmic ray star, whose prongs appeared to be energetic particles, we tried to trace the prongs to the end. A similar procedure was followed in the case of 4-fold stars, whose one prong was grey or black, while the three others were thin to grey. In addition, whenever we came across a π-μ-e we tried to trace backwards. So far we have succeeded in observing 4 τ-mesons. Three of them were traced from stars and one backwards from the π-μ-e ending. Many other interesting events are also observed, stars, very long singles in one emulsion sheet, and rare events. These will be described in another paper. Our main object in this paper is to describe the 4 τ-meson events we have observed so far.

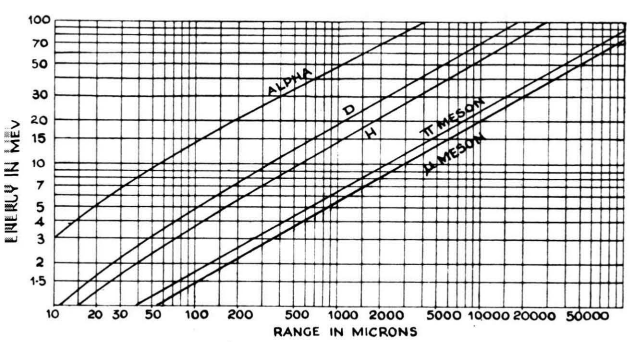

Fig. 1. Range-energy relation for Ilford G 5 plates.

The data obtained from the long range single tracks (some of them as long as 97 mm) all lying in one emulsion sheet, as well as our previous data about single tracks, also from Ilford G 5 plates, enabled us to construct Fig. 1. This figure gives the range-energy relation for α-particles, deuterons, protons, π-mesons, and μ-mesons measured by us in Ilford G 5 emulsions. In computing the energy of particles, advantage is taken of grain density, Coulomb scattering and gap length measurements. The energies of the disintegration products of the τ-mesons, reported here, are calculated with the help of this figure.

In our stack the particles travel through glass, emulsion and air. The ranges given in this paper are all equivalent ranges in the emulsion. In making such conversions, the air correction is neglected as the stopping power of 2000 microns of air is roughly equivalent to that of 1 micron of emulsion [1]. The conversion of the range in glass to the range in emulsion was done with the help of the formula given by Livingston and Bethe [2] for the average loss of energy $-\mathrm{d}E/\mathrm{d}X$. This formula assumes that the energy is mainly lost in ionisation and excitation of the absorber atoms. This assumption is very nearly valid for the energies (less than 100 MeV) which we are considering in this paper. Our results show that the range of 30 MeV protons in glass is about 20,5 % greater than in emulsion. When we once know the relation between the relative ranges in glass and emulsion for protons, it is quite easy to calculate the corresponding ranges for other par-

[1] A. Beiser, Rev. Mod. Phys. **24**, 273 [1952].

[2] M. S. Livingston, and H. A. Bethe, Rev. Mod. Phys. **9**, 245 [1937].

ticles. The relative ranges for two particles of identical velocity are given by

$$R_b/R_a = (Z_a/Z_b)^2 \, (M_b/M_a) ,$$

where R, Z and M denote the range, the charge and the mass respectively.

Event No. 1: In all the τ-meson observations made so far it has been possible to trace either one or two of the disintegration products to their end, and they have been identified either as a π^+ or a π^-. It is, therefore, assumed that all the three disintegration products are π's. The principles of conservation of momentum and energy are then applied and the mass of τ-meson calculated. Fortunately event No. 1 is an event in which it is possible to trace all the three disintegration particles to the end of their range. A τ-meson makes an angle of about $63^0 \pm 2^0$ with the plane of the emulsion and disintegrates into three particles (Fig. 2*). In the figure this short τ-meson track is not shown. One of the disintegration particles lies in the plane of the emulsion and after travelling a distance of 542 microns gives rise to a positive electron, with a grain density of 16 ± 1 grains/50 μ. The nature of this particle is identified and it is a μ^+-meson with an energy of 3,7 MeV. Out of the two other particles the one which goes towards "6,30 o'clock" has a grain density of 21 ± 1 grains/50 μ and the other which goes towards "12,00 o'clock" has a grain density of 18 ± 1 grains/50 μ. The plane of the event makes an angle of 28^0 with the plane of the emulsion. Luckily these two energetic particles can be traced through succeeding emulsion layers. One of them can be traced to an equivalent range of 28,9 mm where it is brought to rest showing a typical π^--ending (Fig. 3). The other particle can be traced to an equivalent range of 38,7 mm where it shows a typical π-μ-e ending (Fig. 4) and can be identified as a π^+. The energy of these two particles at the origin works out as 43,3 MeV and 51,2 MeV respectively. Thus the Q value comes out as 98,2 MeV giving the mass of the τ-meson as 954 ± 6 electron masses. The three angles are: π^-, μ: $74^050 \pm 0^020'$, μ, π^+: $118^010' \pm 0^020'$ and π^+, π^-: $166^030' \pm 0^020'$, that is the three disintegration products are coplanar to within the accuracy of the measurements. If v is the velocity of the μ-meson the principle of conservation of momentum gives the velocity of π^+ and π^- in terms of v and hence their energies can be calculated as multiples of μ-meson energy, they come out as 51,9 MeV and 43,5 MeV. These values are nearly equal to those determined from the energy-range relation. The grain counts in the neighbourhood of the origin, already mentioned, give the estimated values of the energy of these two particles at 55 MeV and 45 MeV respectively. This clearly shows that the event observed is a $\tau^+ \to \pi^+ + \pi^- + \mu^+$ disintegration.

If what we have called a μ-meson were to be a π-meson and what we have called an electron were to be a μ-meson with a grain density of 16 ± 1 grains/50 μ, its energy would be about 65 MeV and it would certainly be possible to trace this particle through successive emulsion layers. But as a matter of fact the particle cannot be traced beyond this point. Thus it is extremely unlikely to be anything else than an electron.

Event No. 2: In the second event the τ-meson makes an angle of $81^0 \pm 3^0$ with the plane of the emulsion. The three disintegration tracks lie in a plane making an angle of $10^020'$ with the plane of the emulsion. Two of these particles have been traced to the end of their range and are identified as π^+ and π^- from their π-μ-e ending and a fourfold star produced by π^-, the π^- being one of the prongs. The third particle has been traced up to 54,05 mm. After this point it goes out of the emulsion layer and it cannot be traced in the next emulsion layer. This fact indicates that its range is greater than 54,05 mm, and less than 69,3 mm. Let us call this third particle the X-particle. The angles between the three disintegrating particles are: X, π^-: $122^010' \pm 0^020'$, π^-, π^+: $98^030' \pm 0^020'$ and π^+, X: $138^050' \pm 0^020'$; that is the three disintegration tracks are coplanar to within the experimental accuracy. Assuming that the third particle is a μ-meson and applying the laws of conservation of momentum we get the energies of the three particles, π^- as 18,0 MeV, π^+ as 30,0 MeV and μ as 53,5 MeV. The range of π^- is 6,09 mm and the corresponding energy is 18,0 MeV. This value of energy is also confirmed from the grain density at the beginning of the π^- track, which is 35 ± 1 grains/50 μ. The range of π^+ is 15,05 mm and the corresponding energy is 30,0 MeV; this value of energy is also confirmed from the grain density measurement of 27 ± 1 grains/50 μ at the beginning of the π^+ track. The energy of the X-particle which we have assumed to be a μ-meson comes out as 53,5 MeV. A μ-meson with this energy would have a range of 56,5 mm and a grain density in the

* Fig. 2—4 auf Tafel S. 340 b.

beginning of 17 grains/50 μ. These estimated values of range and grain density should be compared with the experimental range lying between 54,05 mm and 69,3 mm and the observed density of 33 $\pm$ 2 grains/100 μ. Now making the alternative assumption that the X-particle is a π-meson, and applying the principle of conversation of momentum, we get the energies; π^- as 18,0 MeV and π^+ as 30,0 MeV as before; but now the energy of this third π-meson comes out as 40,8 MeV. A π-meson of energy 40,8 MeV should have a range of 25,8 mm and a grain density of 48 grains/100 μ. When these values are compared with the observed range greater than 54,05 mm and the track density of 33 $\pm$ 2 grains/100 μ, it becomes quite obvious that the third particle cannot be a π-meson and is almost certainly a μ-meson. The corresponding Q value is 101,5 MeV which gives the mass of this τ-meson as 960 $\pm$ 6 electron masses. The limit of accuracy depends on the maximum error in range and hence energy determinations.

Event No. 3: In the third event the τ-meson can be traced to its origin. It is produced from a star with 8 prongs, the τ-prong being one of them. It has a range of 1879 microns and disintegrates into three particles, which are coplanar to within 1^0. The three disintegrating particles lie in a plane which is almost perpendicular to the plane of the emulsion. Two of these particles can be traced to the end of their range. They are identified as a π^+ and a π^- mesons from the π-μ-e and a knock on (a small thick track like an α-track from a radioactive nucleus) produced by the π^-. The energies of these mesons as calculated from their ranges are 27,3 MeV and 47,9 MeV. The angles between the tracks of the three disintegrating particles are $90^0 30' \pm 0^0 20'$, $139^0 10' \pm 0^0 20'$ and $131^0 20' \pm 0^0 20'$. The principle of the conservation of momentum gives for the third particle an energy of 20,6 MeV if it is assumed to be a π-meson, and an energy of 27,1 MeV if it is a μ-meson. The range of a π-meson of energy 20,6 MeV would be 7,8 mm and that of a μ-meson of energy 27,1 MeV would be 17,05 mm. This third particle can be traced to 7,75 mm. It could have been traced again, if it was travelling in the same direction without any deviation between 11,65 mm and 12,35 mm and again between 16,25 mm and 16,95 mm. We have however failed to trace this particle beyond 7,75 mm. The range evidence thus either means that the third particle is a π-meson or if it is a μ-meson it has been deflected from its original direction. We should however like to point out that if this third particle were a π-meson, its energy would have to be 20,6 MeV and the corresponding range only 7,8 mm, which means that the point, 7,75 mm up to to which we have been able to trace this particle, is only within 50 microns of the end of the range of the π-meson concerned. It should, therefore, at this point show a considerable increase in the grain density. This thickening of grains is not only absent but the actual grain density at this point is 62 $\pm$ 2 grains/100 μ, which indicates that the particle has still appreciable energy left over. Further the grain density at the beginning of this third track is 52 $\pm$ 2 grains/100 μ which appears to indicate that this particle is a μ-meson. Because a π-meson of energy 20,6 MeV should show a grain density of 68 grains/100 μ, while a μ-meson with energy 27,1 MeV should show a grain density of 52 grains/100 μ. Thus the range evidence in this case is rather inconclusive but the grain density both in the beginning and also at 7,75 mm strongly supports the view that this third particle is a μ-meson. The corresponding Q value is 102,3 MeV, which gives for the mass of the τ-Meson the value 962 $\pm$ 6 electron masses.

Event No. 4: The fourth τ-meson appears in the outermost emulsion layer, and it is not possible to trace any of the disintegration products beyond this emulsion layer. The lengths of the tracks are 575 microns, 1129 microns and 937 microns. The corresponding angles can also be measured. But as none of the disintegrating particles can be traced to the end of its range, it is not possible to draw a definite conclusion about their nature. We therefore prefer only to report the event. The general appearance of this τ-meson event is rather similar to the τ-meson event reported by Hodgson[3].

Thus three out of the four τ-meson events observed by us appear to establish the fact that a τ-meson can disintegrate into two π-mesons and one μ-meson. The mean value of the τ-meson mass calculated from these events comes out as 959 $\pm$ 10 electron masses.

For exposing the nuclear emulsions on the Gilman's point and getting them back and also for helping in the transport from Bombay to Nairobi and back, I am deeply indebted to Messrs. A. B. Pant, B. N. Nanda, R. K. Pradhan, and I. C. Haslam, all members of the Ministry of External Affairs of the Government of India, Messrs. H. Pandit, H. Vajaria, S. Sapra, and M. Nagpaul, all Indian nationals resident in Kenya, the Kilimanjaro Geological Expedition of the Government of Tanganyika, and the Hindu Mandal of Moshi.

[3] P. E. Hodgson, Phil. Mag. **42**, 1060 [1951].