Occhialini, who developed the emulsion; the Italian Navy and Air Force for their invaluable co-operation; and Mr C. Sgarbi, the scanner, who found the event.

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AN EXAMPLE OF A τ-MESON GENERATED IN A NUCLEAR ENCOUNTER AT HIGH ENERGY

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[Plate 13]

In one of a sandwich of two Ilford G5 plates $1200\,\mu$ thick, exposed emulsion to emulsion at an altitude of 90000 ft. for $5\frac{1}{2}$ h, and at a geomagnetic latitude of 40° N in one of the Sardinian flights of 1952, a τ-meson was observed to have been emitted from a nuclear disintegration. In the adjacent plate the τ-meson was brought to rest and subsequently decayed. A photograph of the tracks is shown in figure 41, plate 13.

The star is comprised of ten minimum tracks, one of which may be attributed to the primary, three black tracks, and one grey track (that due to the τ-meson). The 'primary' and axis of the shower are inclined at 60° with respect to the plane of the emulsion, thus permitting no direct energy measurements; however, considering the median angle of the shower and its multiplicity, the primary energy has been estimated to be at least 30 GeV.

In order to establish definitely the correlation between the events, the two plates were fixed in their relative positions by noting in each the position of traversing heavy nuclei of the cosmic radiation. Large areas near the points of exit and entrance of this particle were searched in the respective plates; the only correlated track for M' was M and conversely. Moreover, the continuation of track B of the disintegration of the τ-meson was found in the opposite plate. As final confirmation, the 'particles' producing tracks M' and M were found to have approximately the same mass. The details of these measurements will now be discussed.

The mass of the particle producing track M, as determined by multiple scattering and range measurements, was $890 \pm 270\,m_e$. Mass determination by gap length and range measurements was not attempted; irregularities in processing of both plates resulting in the 'etching' of tracks in the surface layers, and non-uniformity in development of the lower layers of the emulsion, prejudiced the application of this latter method.

The mass of the particle producing track M' was determined from measurements of multiple scattering over its track length in this plate, and grain density over a length of $800\,\mu$ near the star where the development gradient in the emulsion was small. In order to determine the specific ionization loss from this grain-density measurement, five comparison tracks produced by particles with known mass and charge were selected. The ranges, R_0, at which the grain densities of these tracks were equal to that of track M' were determined and have been listed in column 2 of table 27. Particles with the same specific ionization have equal ratios of mass to range; therefore we may write:

$$\frac{m_0}{R_0} = \frac{m_x}{R_x}$$

where m_x is the mass of the particle producing track M', R_x is its residual range $400\,\mu$ from the star, and where m_0/R_0 is the ratio of mass to range for the 'comparison' particles. R_x may be expressed as a function of m_x, $\bar{\alpha}_{100}$ the mean angle of multiple scattering, and l the total length of the track. We may therefore solve the previous equation for $m_x = f(m_0/R_0, \bar{\alpha}_{100}, l)$ and may calculate m_x for each comparison track. These values have been listed in table 27. The resultant mean value for the mass of the particle producing track M' is $990 \pm 120\, m_e$.

Table 27

particle	range in mm R_0	mass in m_e m_x
proton	$12{\cdot}3 \pm 2{\cdot}0$	1030 ± 140
proton	$12{\cdot}5 \pm 2{\cdot}0$	1012 ± 135
μ-meson	$1{\cdot}56 \pm 0{\cdot}30$	976 ± 145
μ-meson	$1{\cdot}78 \pm 0{\cdot}34$	883 ± 130
π-meson	$1{\cdot}79 \pm 0{\cdot}25$	1050 ± 120

With the correlation between tracks M and M' thus confirmed, we may assume that one is a continuation of the other, and from the measurements of multiple scattering, grain density and range, a more accurate estimate of the mass may be made. The mass of the τ-meson determined by these measurements was $955 \pm 100\, m_e$.

In following the τ-meson along its range of $7300\,\mu$ an angular deviation of 21° was seen to have occurred $1800\,\mu$ from the star. This could be considered as a possible decay in flight of a heavier meson. However, in comparing the grain density and the multiple scattering before and after the deviation it was found that, within experimental error, no change in the velocity or the energy of the particle occurred at this point. We have therefore interpreted this deviation as a single scattering of the meson.

Analysis of the decay

At the end of its range, the τ-meson is seen to have decayed into three charged particles corresponding to tracks A, B and C. These tracks, near the point of the decay, were found to have been co-planar to within 1°. The particles were emitted with the following angles in this plane:

$$\alpha_{AB} = 142°, \quad \alpha_{BC} = 103°, \quad \alpha_{AC} = 115°$$

Their track lengths in the plates were 4100, 2890 and 1800 μ, respectively.

From measurements of multiple scattering and grain density on the tracks of the three decay particles (assuming them to be π-mesons) an average energy value for each was obtained. These values have been listed in table 28 together with the resultant energy value for the decay, Q. From this Q-value a more accurate mass for the τ-meson, $m_x = 975 \pm 12 m_e$, was obtained.

TABLE 28

track	kinetic energy in (MeV): scattering measurements	ionization measurements	mean value
A	$28{\cdot}0 \pm 3{\cdot}5$	$32{\cdot}5 \pm 2{\cdot}3$	$30{\cdot}3 \pm 2{\cdot}3$
B	$34{\cdot}0 \pm 6{\cdot}0$	$26{\cdot}0 \pm 5{\cdot}0$	$30{\cdot}0 \pm 4{\cdot}0$
C	$16{\cdot}5 \pm 2{\cdot}6$	$18{\cdot}4 \pm 1{\cdot}0$	$17{\cdot}9 \pm 1{\cdot}3$

$Q = 78{\cdot}2 \pm 4{\cdot}8$ MeV

TABLE 29

track	kinetic energy (MeV): based on *A*	based on *B*	based on *C*
A	*30·3*	34·0	40·5
B	27·0	*30·0*	36·0
C	13·0	15·5	*17·9*
Q-value	70·3	79·5	94·4

$Q_{\text{av.}} = 81{\cdot}4$ MeV

TABLE 30

identity			kinetic energy (MeV)					*Q*-value (MeV)	
				track *B*		track *C*			
A	*B*	*C*	track *A*	calc.	exp.	calc.	exp.	calc.	exp.
π	π	π	30·3	27·0	$30{\cdot}0 \pm 4{\cdot}0$	13·0	$17{\cdot}9 \pm 1{\cdot}3$	70·0	78·2
π	π	μ	30·3	27·0	$30{\cdot}0 \pm 4{\cdot}0$	16·5	$14{\cdot}8 \pm 1{\cdot}3$	73·0	75·1

The Q-value may also be determined by considering a momentum balance for three π-particles, based successively on their mean energy values listed in table 28. The results of such an analysis have been listed in table 29, together with the mean value of the Q determined by this means.

In order to identify the decay particles, an analysis applying the conservation of momentum has been considered. This analysis was made assuming, alternatively, that tracks A, B and C were produced by π- and μ-mesons. The momentum balance was based on the momentum values deduced from the measurements made on track A which were considered to be the most reliable. The two combinations that appeared most consistent have been listed in table 30. The possibility, however, that

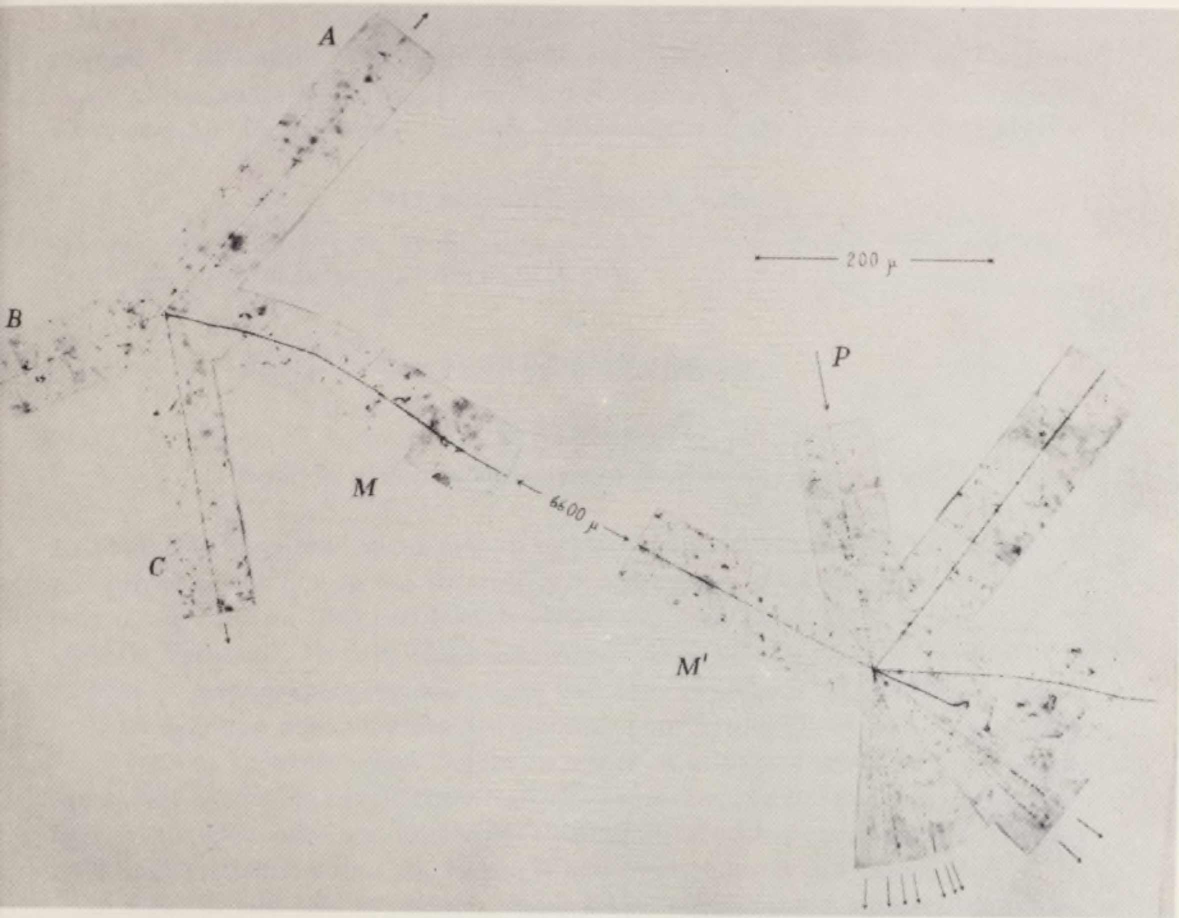

FIGURE 41

one of the particles was a μ-meson is not considered very likely owing to the possible existence of systematic errors in the grain density determinations in these plates, and to the contrary evidence obtained in the analysis of the other τ-meson events (see references).

We would like to express our appreciation to Mr A. Bernardi for his aid in the analysis of this event. We would also like to take this opportunity to thank the many participants in the Sardinian flights of 1952 and in particular the Italian Navy and Air Forces, whose valuable collaboration made the expedition possible.

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THE PRODUCTION OF τ-MESONS

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In 1950, Harding found two τ-mesons in plates exposed to the cosmic radiation at a depth of about 3 m in the ice on the Jungfraujoch plateau. At that time the only other τ-meson that had been reported was that found by the Bristol group (Brown, Camerini, Fowler, Muirhead, Powell & Ritson 1949) in a much greater volume of photographic emulsion than had been examined by Harding (1950).

This suggested that τ-mesons are emitted more frequently from hydrogen than from heavier elements when similar numbers of energetic particles are incident upon them (Hodgson 1951). The τ-mesons are presumably produced in high-energy nucleon-nucleon collisions, and when this happens inside heavy nuclei there may be a high probability that the meson is absorbed before it can escape.

In order to test this hypothesis, more plates were exposed surrounded by ice, and one further τ-meson has been found (Hodgson 1951; Herz, Hodgson & Tennent 1953). This provides additional support for the hypothesis.

Since these results were obtained, several more τ-mesons have been found in plates exposed under various conditions (Fowler, Menon, Powell & Rochat 1951; Ceccarelli, Dallaporta, Merlin & Rostagni 1952). It is the purpose of this note to discuss the bearing of this new evidence on the hypothesis of favoured emission from hydrogen, and to suggest some experiments which could be made to investigate τ-meson production in more detail.

The number of τ-mesons found in plates exposed with little hydrogenous matter surrounding them, such as those in high-altitude flights, makes it almost certain that τ-mesons can be emitted from nuclei other than hydrogen. This is what would be expected even if τ-mesons interact very strongly with nuclear matter, since it is known that energetic peripheral collisions can occur without exciting the remainder of the nucleus. If a τ-meson were produced in such a collision it would have a high probability of escape.