Cloud-Chamber Evidence for a Charged Counterpart of the θ^0 Particle*

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A photograph obtained in a Wilson cloud chamber, operated in a magnetic field, shows the following unusual event: A positive particle, produced in an interaction above the cloud chamber, decays in flight into a positive particle less massive than a K meson. Four other lightly ionizing particles also originate from the decay point; these appear in the form of two small-angle pairs, each pair consisting of one positive and one negative particle. The observed momenta and ionizations are consistent with three of these four particles being either electrons or mesons; the fourth must be an electron.

The event may be interpreted as the decay:

$$K^+ \to \binom{\pi^+}{\mu^+} + \pi^0 + Q \text{ Mev},$$

followed by the decay of the π^0 meson into four electrons (a possible but hitherto unobserved mode of decay):

$$\pi^0 \to e^+ + e^- + e^+ + e^-.$$

This interpretation leads to a remarkable internal consistency of the data and is supported by the following experimental facts:

(i) There is good overall transverse-momentum balance in two mutually perpendicular planes.

(ii) If we assume that all the particles in the above group of four are electrons resulting from the decay of a neutral particle the mass of the latter, determined from energy-momentum balance, is $(255_{-10}^{+15})m_e$, in good agreement with the known mass of the π^0 meson.

(iii) A transformation to the rest system of the π^0 meson shows that in this frame the four electrons come off as two small-angle pairs traveling in opposite directions. This is the most probable configuration in the four-electron decay of a π^0 meson.

The Q values calculated for the K^+ decay are: $Q(\pi^+,\pi^0) = (213_{-10}^{+15})$ Mev and $Q(\mu^+,\pi^0) = (207_{-10}^{+15})$ Mev. Comparison of the first Q values with that for the θ^0 particle $Q(\pi^+,\pi^-) = 214 \pm 5$ Mev, suggests that the unstable meson observed in this event and designated phenomenologically above as a K^+ meson may be a charged counterpart of the θ^0 particle.

This interpretation may explain at least some of the cases, observed by other workers, in which γ rays appear to be associated with S particles.

Other possible interpretations of the event are considered.

1. INTRODUCTION

DURING the course of an investigation of the unstable particles produced in cosmic-ray nuclear interactions, the unusual cloud-chamber photograph shown in Fig. 1 was obtained.[1] A particle (No. 1) enters the cloud chamber and is believed to decay; five ionizing tracks (Nos. 2, 3, 4, 5, 6) diverge from the decay point. An enlargement of the region around this point is shown in Fig. 2. The details of this event are presented in this paper and possible interpretations are considered.

2. EXPERIMENTAL DETAILS

The event was photographed in a Wilson cloud chamber operated in a magnetic field of 5500 gauss at Echo Lake, Colorado (altitude 10 700 ft). The illuminated region of the chamber has average dimensions, 16 in.×16 in.×5 in. The cloud chamber was expanded by coincidences between two proportional counter trays, one placed immediately above the chamber and one beneath it. The counter system was designed to detect penetrating showers produced in a layer of lead $6\frac{1}{2}$ in. thick placed above the chamber. Two photographs were taken at a stereo angle of 17° on Kodak Linagraph Panchromatic 70-mm film, using two matched $3\frac{1}{2}$ in. Goertz Dagor lenses at an aperture of $f/19$. The cloud chamber was filled with argon and saturated with the vapor of a 70 percent–30 percent mixture of ethyl alcohol and water; the total pressure in the compressed position was 82.8 cm of mercury.

The photograph shown in Fig. 1 is one of 30 000 photographs so far taken with this cloud chamber, using various proportional-counter trigger schemes to detect penetrating showers. In this set of photographs 270 V^0 particle decays and 60 $V^\pm$ decays were observed.

3. ANALYSIS PROCEDURE

The two stereo photographs of the event shown in Fig. 1 were reprojected through a glass plate onto a screen perpendicular to the axes of the two camera lenses. The thickness of this glass plate was equal to the total thickness of a double window arrangement through which the photographs were taken. The two negatives were first aligned in the stereo projector so that the images of a series of horizontal and vertical fiducial lines ruled on the inside of the front window of the cloud chamber (see Fig. 1) appeared stationary on the screen when the two views were projected alternately. For this alignment the screen-film distance was set equal to the correct fiducial plane-film distance. The apparent spacing of the fiducial lines was checked against the known spacing to make sure that the negatives were being reprojected at the correct magnification.

The projector was mounted on the table of a small milling machine so that it could be moved in a direction parallel to the axes of the camera lenses (the Z direction) until a particular point on a track appeared stationary when the two views were projected alternately. By

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[1] This event was the subject of a post-deadline paper presented at the Washington Meeting of the American Physical Society, May, 1954. Further details were presented at the Seattle Meeting of the American Physical Society, July, 1954. [D. R. Harris and A. L. Hadson, Phys. Rev. 95, 661(A) (1954)].

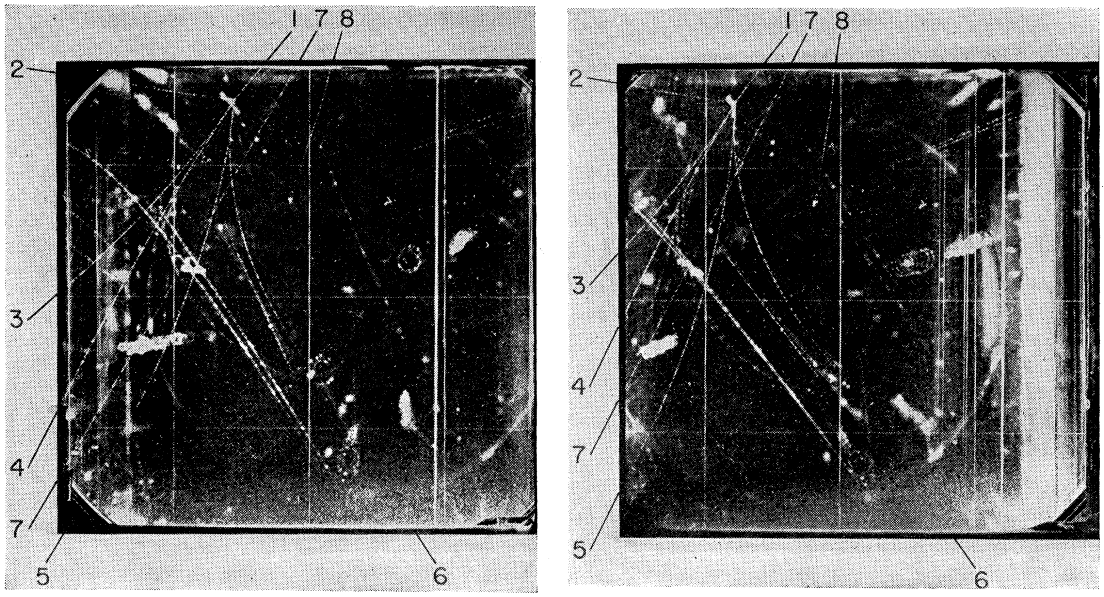

FIG. 1. Stereoscopic views of a cloud-chamber photograph believed to show the decays: $\theta^+ \to \pi^+ + \pi^0$; $\pi^0 \to e^+ + e^- + e^+ + e^-$.

carefully marking the position of this point on a large sheet of paper attached to the screen and repeating the procedure for many points along each track, an orthogonal projection of the event in the plane of the screen (called here the XY plane) was obtained. The apparent Z reading of each point was noted alongside the point as it was plotted. These readings were then converted into true Z readings, taking the fiducial plane as $Z=0$ and correcting each reading for the displacement of the tracks in the Z direction which occurred when the cloud chamber was expanded. Finally, on a drawing board, a YZ and an XZ projection were constructed point by point from the points on the XY projection and their corrected Z values (Fig. 3).

From Fig. 3 it is clear that tracks Nos. 1–6 all meet at one point (M) in the middle of the illuminated region of the cloud chamber. During the reprojection a careful search was made around this point for a possible ionizing recoil fragment. No indication of any such recoil fragment was found. It might be mentioned that

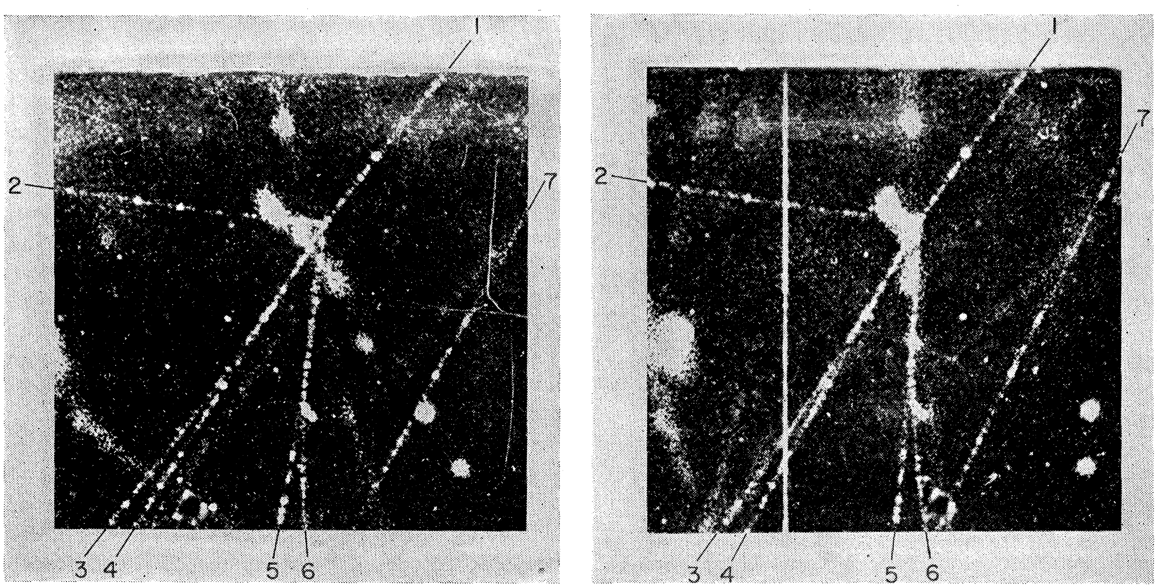

FIG. 2. Enlargement of part of the cloud-chamber photograph shown in Fig. 1.

although a cluster of old ionization partly obscures this region in the right view it is not space-related and the point M is quite clear on reprojection.

For a study of the dynamics of the event shown in Fig. 1 we need to know the directions of the momentum vectors (P) of particles 1–6 at the point M. The directions of these vectors may be defined by the two angles γ and ψ shown in Fig. 4. Thus γ is the angle between the Y axis and the tangent (at the point M) to the projection of the track in the XY plane; ψ is the angle between the Y axis and the tangent to the projection of the track in the YZ plane. The tangents to the tracks in the XY projection were determined in the following manner: For the most highly curved tracks a long compass was set to the correct radius in the XY plane (calculated from the curvature on the film) and the center of curvature was found by graphical construction. The direction of the tangent at M was then found by drawing a radius from the center of curvature to the point M. When the required radius was too large for this method to be practical, a chord was drawn from M and the angle between the tangent and the chord was calculated. The latter method was also used

TABLE I. Basic angle data for event shown in Fig. 1.

Track number	γ (degrees)	ψ (degrees)
1	-33.6 ± 0.3	-19.0 ± 0.7
2	-92.2 ± 0.5	-96.4 ± 1.5
3	-29.5 ± 0.2	-13.3 ± 0.3
4	-29.1 ± 0.2	-13.6 ± 0.3
5	$-\ 2.7\pm0.2$	-15.2 ± 0.5
6	$-\ 4.4\pm0.4$	-15.4 ± 0.5

for finding the tangents to the curved projections in the YZ plane. [It may be noted that since the path of a charged particle in a uniform magnetic field is a helix whose axis is the field direction, the projections in the YZ and XZ planes are parts of sine curves, modified here by the transverse field (i.e., the component in the XY plane) and variations of the longitudinal field (i.e., the component in the Z direction) along a track.]

For one track (No. 2), it is impossible to find ψ from the YZ projection. Since this track is nearly horizontal and curving upwards, the projection in the YZ plane is mainly the projection of the upwards curvature. The direction of this track at M was therefore determined by measuring angles with respect to the X axis in the XY and XZ projections. The true value of ψ in the YZ plane was then calculated.

A second observer also measured the angles γ and ψ by an independent method. The space coordinates of three points on each track near the point M were found from direct comparator measurements on the film; the angles γ and ψ were then calculated from these coordinates. For example, γ was found by fitting a circle to the projection of these points in the XY plane and

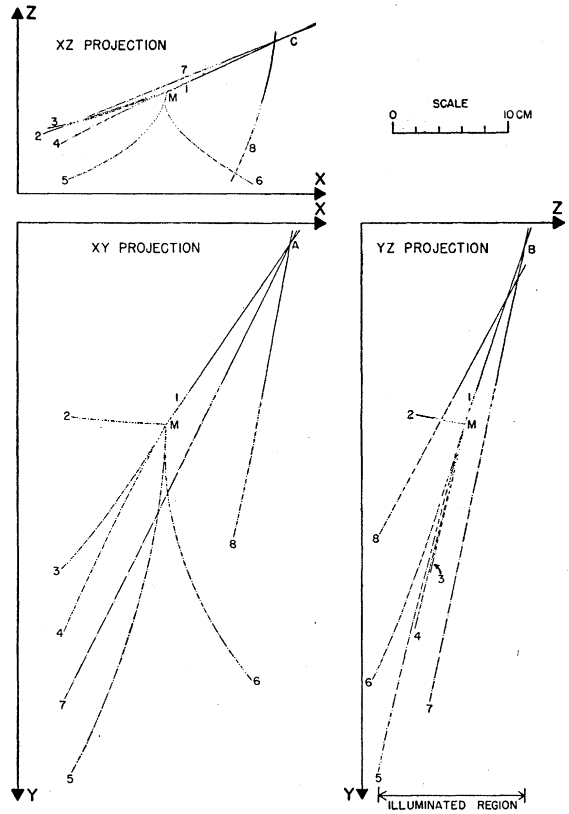

FIG. 3. Orthogonal projections of the tracks in three mutually perpendicular planes.

finding the slope of its tangent at the point M. The two methods gave values for these angles which were in good agreement; the final values of γ and ψ (given in Table I) were therefore obtained by combining the results of both methods. The space angles between various pairs of tracks are given in Table II.

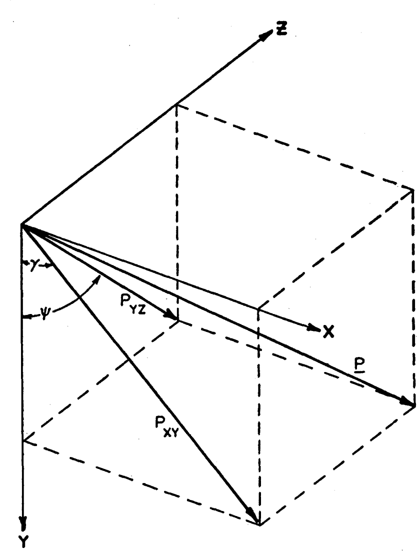

FIG. 4. Coordinate system.

TABLE II. Space angles in the laboratory frame of reference.

Particles m and n	Space angles between particles m and n
1 and 2	55.7°
3 and 4	0.5°
5 and 6	1.7°
1 and "π^0," (see Sec. 5)	11.0°
2 and "π^0"	66.7°

The momenta of particles Nos. 2–6 were obtained by measuring the curvatures of their tracks on the two negatives with a Gaertner comparator (type M1229). Corrections to the observed curvatures were made to allow for the fact that a track image on the film is a conical projection of the actual track in space through the centers of the principal planes of the camera lens onto the plane of the film. Corrections were also made to take into account the effect of transverse components of the magnetic field. The above corrections depend on the length, position, curvature, and orientation of the track in space, the direction of the transverse field and on the ratio of the transverse field to the field in the Z direction; they are, of course, in general quite different for the two views. (The magnetic field data were based on measurements of the components in the X, Y, and Z directions at many points within the volume of the cloud chamber. The measuring equipment, a Pye "Scalamp" fluxmeter, was calibrated at several field values using the proton resonance method.) The magnetic field values used in the calculation of the above corrections and in the calculation of the final momenta were obtained by taking the values of the longitudinal field and the transverse field at three points along each track, then suitably weighting and averaging these three values. (We are indebted to R. W. Williams and G. Ascoli for details of an averaging method which they have developed.)

The momenta of particles Nos. 2–6 are given in Table III. The estimated errors in the momentum values obtained from the left and right views because of the scatter of the readings in the comparator measurements of the curvatures are given in parentheses. It will be seen that, considering these errors, the momentum values obtained from the left and right views after making the above corrections are in satisfactory agreement. The actual percentage corrections that had to be applied to the film curvatures are also given in Table III. The components of the momenta in the XY and YZ planes, denoted by P_{XY} and P_{YZ}, respectively, are given in the last two columns of this table.

4. DISCUSSION OF THE INDIVIDUAL TRACKS

Particle No. 1.—This particle came from an interaction in the lead above the cloud chamber. In the XY projection, track No. 1 and two other tracks (No. 7 and No. 8) of apparently the same age may be extrapolated back to a fairly well-defined origin, A (Fig. 3). In the YZ projection, the extrapolation of tracks No. 1 and No. 7 intersect at a point B whose Y value is consistent with the Y value found for the origin (A) in the XY projection (Fig. 3). Although the extrapolation of track No. 8 in the YZ projection misses point B (probably caused by scattering of particle No. 8 before entering the chamber), it can reasonably be concluded that a nuclear interaction occurred in the lead at or near to the point (A,B) and that particle No. 1 was produced in this interaction.

Unfortunately, since particle No. 1 had a high momentum and its track is very short, it is not possible to determine directly the sign of its charge.

Particles Nos. 2–6.—Upper limits for the masses of these particles can be obtained from their momenta and visual estimates of their ionizations—these limits are given in column 9 of Table III. We see that particle No. 4 was considerably less massive than a proton, that particles Nos. 2, 3, and 5 were light particles (mesons or electrons), and that particle No. 6 must have been an electron. (A μ^- meson with the momentum of particle No. 6 would be ionizing at a rate 3.2 times the minimum value.) Note the very small angles at the point M between (positive) particle No. 3 and (negative) particle No. 4 and between (positive) particle

TABLE III. Measured momenta of particles involved in event shown in Fig. 1.

Particle No.	Sign	Momentum correction (%) Left view	Right view	Corrected total momenta P (Mev/c) From left view	From right view	Mean value	Ionization (×minimum ionization)	Mass from momentum and ionization (m_e)	Probable identity (see Sec. 5)	P_{XY} (Mev/c)	P_{YZ} (Mev/c)
2	+	−10	−24	156	150	153 ±10[b]	<2	< 440	$\pi^+(\mu^+)$	144	50
				(±6.7)[a]							
3	+	+ 1	− 8	131	133.5	132 ± 5[b]	<2	< 370	e^+	130	116
				(±2.6)[a]							
4	−	+ 2	− 6	372.5	363	368 ±35[b]	<2	<1090	e^-	360	324
				(±8.6)[a]							
5	+	− 3	−10	121	121	121 ± 4[b]	<2	< 340	e^+	117	121
				(±0.7)[a]							
6	−	+ 6	+11	52.6	53.5	53.1± 2[b]	<2	< 150	e^-	51	53
				(±0.4)[a]							

[a] Estimated standard deviation in momentum value for each view caused *only* by scatter of readings in comparator measurement of curvature.
[b] Combined errors caused by all sources of uncertainty (see Sec. 5).

No. 5 and the (negative) electron No. 6 (Fig. 1 and Table II).

From the values of P_{XY} and P_{YZ} given in Table III and the values of γ and ψ in Table I, we may obtain the transverse momenta of particles Nos. 2–6 (relative to the direction of particle No. 1) in the XY and YZ planes. The transverse momentum of particle No. 2 in the XY plane is -123.3 Mev/c; the total transverse momentum of particles Nos. 3–6 is $+122.6$ Mev/c. The unbalanced transverse momentum in the XY plane is thus -0.7 ± 10 Mev/c. The corresponding momenta in the YZ plane are -48.8 Mev/c and $+53.3$ Mev/c; the imbalance here is thus $+4.5\pm10$ Mev/c. From the excellent balance of transverse momenta in both the XY and YZ planes it seems very unlikely that the event shown in Fig. 1 also gave rise to any neutral particles or γ rays which have escaped detection.

5. POSSIBLE INTERPRETATION

There is no evidence to suggest that the event was a nuclear interaction in the gas of the cloud chamber. We therefore consider an interpretation based on the decay of a positively charged particle. Although we cannot exclude the direct decay of particle No. 1 into five particles, we will show that the following interpretation is remarkably consistent with the experimental data: Particle No. 1 decayed into a light particle (No. 2) and a π^0 meson, which subsequently decayed into four electrons (Nos. 3, 4, 5, 6).

With the above interpretation, the apparent origin of the five secondary tracks (No. 2–6) at one point is readily explained. Because of the extremely short mean life[2] ($\sim5\times10^{-15}$ sec) of π^0 mesons, the decay points of the positive unstable particle (No. 1) and of the π^0 meson were separated in space by a distance ($\sim8\times10^{-4}$ cm), too small to be resolved in the cloud-chamber photograph.

If we assume that particles Nos. 3–6 were all electrons resulting directly or indirectly (via processes in which energy and momentum losses were negligible) from the decay of a neutral particle, the momentum and mass of this hypothetical neutral particle can be calculated. We find that the four "electrons" were kinematically equivalent to a particle of mass $(255_{-10}^{+15})m_e$ and momentum 662 Mev/c, traveling in the direction specified by $\gamma_0=-22.65°$ and $\psi_0=-14.0°$. This mass value is in such good agreement with the accepted mass of the π^0 meson $(263.7\pm0.7m_e)$[3,4] that, barring an unlikely coincidence, a π^0 meson must indeed have been involved in this event. (The possible processes whereby two negatron-positron "pairs" may result from the decay of a π^0 meson will be discussed later.)

Let us therefore assume that particle No. 1 decayed via the scheme:

$$K^+\rightarrow\binom{\pi^+}{\mu^+}+\pi^0+Q\text{ Mev.}$$

(It must be remembered that the ionization and momentum of particle No. 2 are equally consistent with this particle being either a π^+ or a μ^+ meson; its mass is known only to be less than $440m_e$.) The above two decay schemes give the following values for Q and the mass of particle No. 1:

$$Q(\pi^+,\pi^0)=\left(213\begin{matrix}+15\\-10\end{matrix}\right)\text{ Mev},\quad m_1=\left(954\begin{matrix}+30\\-20\end{matrix}\right)m_e,$$

and

$$Q(\mu^+,\pi^0)=\left(207\begin{matrix}+15\\-10\end{matrix}\right)\text{ Mev},\quad m_1=\left(876\begin{matrix}+30\\-20\end{matrix}\right)m_e,$$

respectively (taking $m_{\pi^+}=273.4m_e$, $m_{\pi^0}=(876_{-20}^{+30})m_e$, and $m_{\mu^+}=207.0m_e$).[3,4]

A comparison of the first Q value, $Q(\pi^+,\pi^0)=(213_{-10}^{+15})m_e$, with the energy released in the decay of the θ^0 particle:[5]

$$\theta^0\rightarrow\pi^++\pi^-+214\pm5\text{ Mev},$$

suggests that particle No. 1 may be a charged counterpart of the θ^0 particle:

$$\theta^+\rightarrow\pi^++\pi^0+\left(213\begin{matrix}+15\\-10\end{matrix}\right)\text{ Mev.}$$

Discussion of Errors

The quoted errors in the mass of the hypothetical neutral particle and in the Q values (approximately a standard deviation in each case) were estimated by considering the errors possible in the angle measurements and the standard deviations in the momenta caused by the scatter of the readings in the comparator measurements of the curvature, to possible distortions in the cloud-chamber tracks, to multiple scattering of the electrons in the gas of the cloud chamber, and to uncertainties in the magnetic field effective on the particles.

In computing the error in the mass of the hypothetical neutral particle, the contribution which is most difficult to estimate is that caused by possible distortions in tracks Nos. 3–6. However, the calculated mass is rather insensitive to such distortions, providing they were reasonably uniform over the region between tracks Nos. 3 and 6. This is so because a distortion which reduces the apparent momentum of a positive particle increases that of a negative particle and *vice versa*, the two changes being partly self-compensating in the analysis of this event. For example, even if the distortion in this particular expansion were such that it would have given a straight track a curvature corresponding

[2] B. M. Amand, Proc. Roy. Soc. (London) **A220**, 183 (1953).
[3] W. Chinowsky and J. Steinberger, Phys. Rev. **93**, 586 (1954)—for $\pi^--\pi^0$ mass difference.
[4] Smith, Birnbaum, and Barkas, Phys. Rev. **91**, 765 (1953)—for π^- mass.
[5] Thompson, Burwell, Cohn, Huggett, and Karzmark, Phys. Rev. **95**, 661 (1954).

to a positive 2-Bev/c particle ("positive distortion") or corresponding to a negative 2-Bev/c particle ("negative distortion"), the correction to the above value of $255m_e$ that this would necessitate would only be $-8m_e$ or $+13m_e$, respectively. From previous experience we know that the distortion is generally negative in this region and that the "distortion momentum" is certainly not less than 2 Bev/c.

The distortions near the top of the cloud chamber are known to be lateral distortions; therefore these are not likely to have much effect on track No. 2 which is nearly horizontal.

The Decay of the π^0 Meson

We must now consider three possible explanations to account for the observation of the two electron "pairs":

(a) The π^0 meson decayed via the scheme

$$\pi^0 \rightarrow \gamma+\gamma, \tag{i}$$

and then the γ rays materialized into negatron-positron pairs in the electromagnetic fields of two nuclei of the gas of the cloud chamber, after traversing distances so short that the apexes of the two pairs cannot be resolved in the photograph from the decay point of the positive unstable particle, No. 1.

The probability of both γ rays materializing within 2 mm, a distance appreciably greater than the track width in the chamber (0.7 mm), is 4×10^{-10}.

(b) The π^0 meson decayed via the scheme

$$\pi^0 \rightarrow e^+ + e^- + \gamma, \tag{ii}$$

and then the γ ray materialized within a distance of 2 mm.

This mode of decay was first suggested theoretically by Dalitz.[6] The occurrence of high-energy pairs of electrons within a few microns' distance from nuclear interactions has been observed in photographic emulsions by Daniel *et al.*,[7] Lord *et al.*,[8] Amand,[2] and Schein *et al.*[9] The frequency of these pairs is about twenty times higher than would be expected if they were caused by the materialization of γ rays produced in decay scheme (i).[2] Under the assumption that all the close pairs are produced by the decay of π^0 mesons via decay scheme (ii), the following values were obtained for the branching ratio

$$\frac{\pi^0 \rightarrow e^+ + e^- + \gamma}{\pi^0 \rightarrow \gamma+\gamma}:$$

0.020 ± 0.006,[7] 0.013 ± 0.004.[2] Lindenfeld *et al.*,[10] using counter techniques, obtained the value $0.0145_{-0.0045}^{+0.008}$. The experimental values are in excellent agreement with the theoretical value, $1/80=0.012$, calculated by Dalitz.[6]

Taking Dalitz' calculated value for the branching ratio, we find the probability that the π^0 meson decayed via scheme (ii) and that the γ ray then materialized within 2 mm is 2.2×10^{-7}.

(c) The π^0 meson decayed into four electrons:

$$\pi^0 \rightarrow e^+ + e^- + e^+ + e^-. \tag{iii}$$

This decay scheme has not previously been observed experimentally. However, the probability for this mode of decay is expected to be about $1/(160)^2 = 4\times 10^{-5}$ times that for a decay into γ rays.[11]

From a comparison of the relative probabilities, $<4\times 10^{-10}$, $<2.2\times 10^{-7}$, and 4×10^{-5}, given above, we conclude that the most probable explanation of the origin of the two electron pairs is the direct decay of the π^0 meson into four electrons. This conclusion is supported by a comparison of the angular relationship of the four electrons in the rest system of the π^0 meson with that expected theoretically. The most likely decay configuration in the rest system of a π^0 meson is one in which the four electrons form two small-angle pairs which travel in opposite directions and which have essentially equal total energies. The angles between the pairs, observed in this event, in the rest system of the π^0 meson and the total energies of the electrons in this system are given in Table IV.

A determination of the angle between the two planes defined by the pairs at the decay point would be of interest, but unfortunately it has not been found possible. A worthwhile determination would necessitate a much more accurate knowledge of the original directions of the electrons at the decay point since the opening angles of the pairs are so small; this is difficult to achieve since the magnetic field causes the electrons to lose rapidly their original directions.

6. OTHER ATTEMPTS AT INTERPRETING THIS EVENT

It is necessary to inquire whether there is some other interpretation of the event shown in Fig. 1 which is as consistent with the experimental data as the interpretation given above.

TABLE IV. Energies and angles in the rest system of the π^0 meson.

Particle	Energy (Mev)	Space angle
3	17.9	$\theta_{3,4}=3.8\pm 2.2°$
4	48.3	
5	46.3	$\theta_{5,6}=4.6\pm 1.4°$
6	17.9	

[6] R. H. Dalitz, Proc. Phys. Soc. (London) **A64**, 667 (1951).

[7] Daniel, Davies, Mulvey, and Perkins, Phil. Mag. **43**, 753 (1952).

[8] Lord, Fainberg, Haskin, and Schein, Phys. Rev. **87**, 538 (1952).

[9] Schein, Fainberg, Haskin, and Glasser, Phys. Rev. **91**, 973 (1953).

[10] Lindenfeld, Sachs, and Steinberger, Phys. Rev. **89**, 531 (1953).

[11] R. H. Dalitz (private communication). This estimate neglects exchange terms; however, these are expected to be fairly small.

Let us examine the possibility of the initial decay being that of a τ^+ meson, via the decay mode recently observed by Crussard *et al.*:[12]

$$\tau^+ \rightarrow \pi^+ + \pi^0 + \pi^0.^{13}$$

Since there is good evidence that all four electrons came from only one π^0 meson, the τ^+ decay would have had to satisfy the requirement of transverse momentum balance between the π^+ meson and only one π^0 meson. (The measured transverse momenta of particle No. 2 and the π^0 meson are 126.2 Mev/c and 126.6 Mev/c, respectively.) This, of course, could obtain if the other π^0 meson happened to travel in a direction close to the line of flight of the τ^+ meson before decay. However, the maximum apparent Q value for such a decay, if analyzed as a two-body decay, is $Q(\pi^+,\pi^0)=84$ Mev, whereas the observed value is $Q(\pi^+,\pi^0)=(213_{-10}^{+15})$ Mev. Thus the event shown in Fig. 1 cannot be caused by the decay:

$$\tau^+ \rightarrow \pi^+ + \pi^0 + \pi^0 + 84 \text{ Mev}.$$

Any explanation of this event on the basis of a purely electromagnetic interaction, such as direct production of two electron pairs in the field of an argon nucleus, is extremely improbable because the electron pairs would have to appear kinematically equivalent to a π^0 meson.

7. SUMMARY AND CONCLUDING REMARKS

The cloud-chamber photograph shown in Fig. 1 can be interpreted in the following way: A heavy meson (designated phenomenologically as a K^+ meson) decayed into a light meson and a π^0 meson. The π^0 meson then decayed, most probably "directly," into four electrons. A comparison of the energy released in the decay of this K^+ meson, $Q(\pi^+,\pi^0)=(213_{-10}^{+15})$ Mev, with that released in the decay of a θ^0 particle, $Q(\pi^+,\pi^-) = (214\pm5)$ Mev, suggests that this K^+ meson may be a charged counterpart of the θ^0 particle:

$$\theta^+ \rightarrow \pi^+ + \pi^0 + \left(213\begin{matrix}+15\\ \\ -10\end{matrix}\right) \text{ Mev}.$$

The mass value corresponding to this decay scheme is $(954_{-20}^{+30})m_e$; the momentum of the π^+ meson and the π^0 meson in the rest system of the θ^+ particle is

$$p^*(\pi^+,\pi^0)=(201_{-6}^{+9}) \text{ Mev}/c.$$

If the above interpretation is correct and θ^+ particles do indeed exist, they must be responsible for some of the V^+ decay events which have been observed. Charged π mesons have already been identified among the decay products of charged V particles and S particles.[14–17] θ^+ particles may also be responsible for at least some of the events, observed by other workers,[18] in which γ rays appear to be associated with S particles.

The π^0 meson emitted in the decay of a θ^+ particle will usually disintegrate into two γ rays and so escape detection, unless the event occurs in a multiplate cloud chamber or a thick stack of photographic emulsions. However, on the average about 1 in 80 decays of θ^+ particles should show two electrons coming from the decay point, because of the decay mode: $\pi^0 \rightarrow e^+ + e^- + \gamma$. The fact that this type of event has not been observed before the much rarer decay into four electrons must be attributed to an unusual statistical fluctuation.

If our interpretation is correct we can calculate an upper limit to the *average* rate at which events similar to that shown in Fig. 1 should be observed in the future. With the present experimental arrangement, we observe about one charged V particle decay in 500 cloud-chamber photographs. Since all these events cannot be attributed to θ^+ particles and since, on the average, only one π^0 meson in 2.6×10^4 will decay into four electrons, an upper limit to the above rate is one event in $500\times2.6\times10^4=13\times10^6$ cloud-chamber photographs! It may eventually be possible to increase the present detection efficiency for decay events but, in any case, photographs similar to that shown in Fig. 1 are likely to remain extremely rare.

[12] Crussard, Kaplon, Klarmann, and Noon, Phys. Rev. **93**, 253 (1954).

[13] The Q value expected for this mode of decay is 84 Mev, if one assumes the mass of the τ^+ meson to be $965m_e$.

[14] H. S. Bridge and M. Annis, Phys. Rev. **82**, 445 (1951).

[15] C. C. Butler, Report of the Bagnères de Bigorre Conference 1953 (unpublished), p. 90.

[16] Gregory, Lagarrigue, Leprince-Ringuet, Muller, and Peyrou, Nuovo cimento **11**, 292 (1954).

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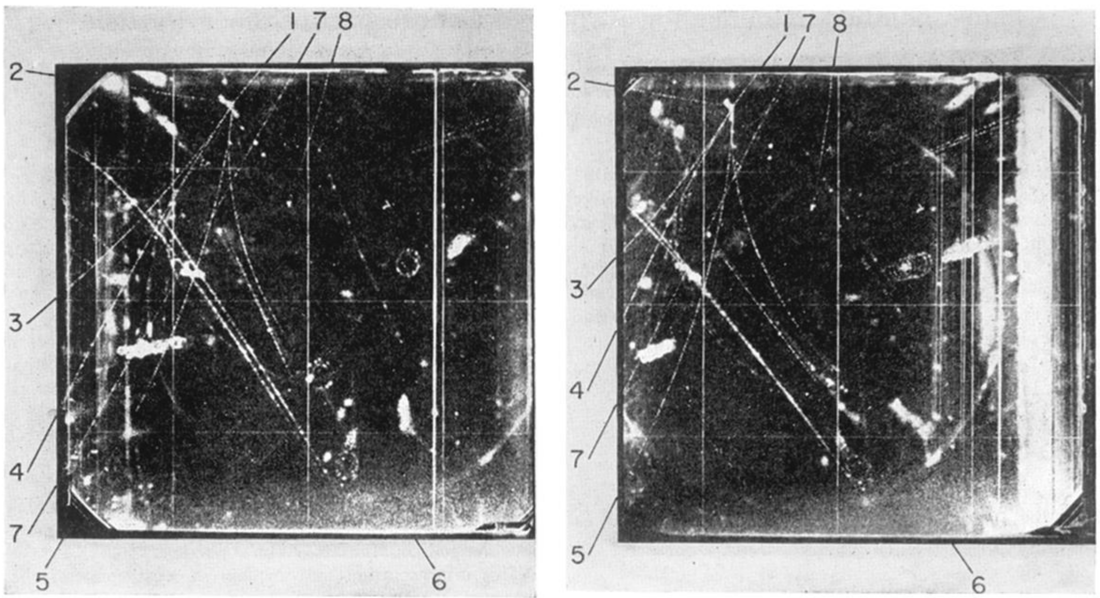

FIG. 1. Stereoscopic views of a cloud-chamber photograph believed to show the decays:
$\theta^+ \rightarrow \pi^+ + \pi^0;\quad \pi^0 \rightarrow e^+ + e^- + e^+ + e^-$.

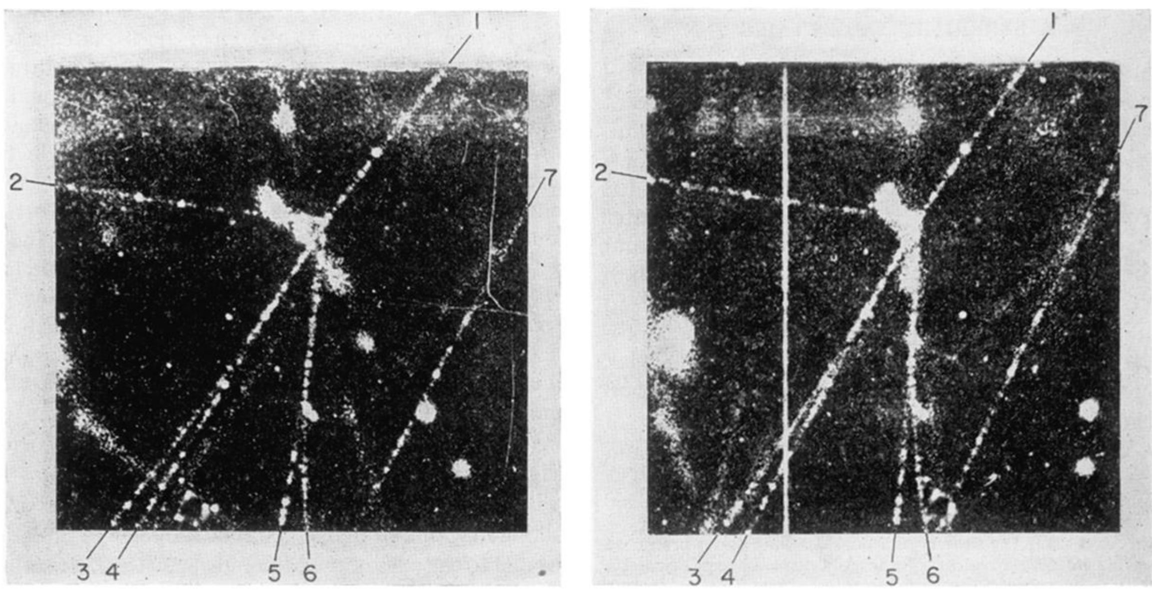

FIG. 2. Enlargement of part of the cloud-chamber photograph shown in Fig. 1.