Cloud-Chamber Observations of Some Unusual Neutral *V* Particles Having Light Secondaries*

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From six cloud-chamber photographs of unusual V^0 decay events, the following conclusions are drawn: (1) there is a neutral V particle that decays into two particles lighter than κ mesons with a Q value too small to be consistent with a $\theta^0(\pi, \pi, 214 \text{ Mev})$ particle; (2) some of these events cannot be explained in terms of the decay of a $\tau^0(\pi^0, \pi^-, \pi^+, Q{\sim}80 \text{ Mev})$ particle; (3) these events can be explained by any one of a number of three-body decay schemes, but two different types of V particles must be postulated if two-body decays are assumed.

I. INTRODUCTION

Since the discovery of neutral V particles it has become clear that at least two decay schemes must be postulated to explain the experimental data. The majority of V^0 decay events can be interpreted in terms of a decay into a proton and a negative π meson as the observable secondaries: $\Lambda^0 \rightarrow p^+ + \pi^-$. Many laboratories have also observed decays which cannot be interpreted in terms of the Λ^0 mode because the ionization and momentum of the positive decay product imply a mass smaller than the proton mass. The work of Thompson and others has established that a large fraction of these V^0 decays are consistent with the decay scheme $\theta^0 \rightarrow \pi^\pm + \pi^\pm$ (or $\mu^\mp$) with an energy release $Q(\pi,\pi) = 214 \pm 5$ Mev.[1] The Caltech group also observes that most of the cases in which the positive secondary is lighter than a proton are consistent with the above θ^0 decay scheme.

However, many laboratories have observed decays which cannot be Λ^0 decays, and for which $Q(\pi,\pi)$ is clearly less than 200 Mev.[1-5] Some of these cases can be explained by the decay scheme $V_3{}^0 \rightarrow \pi^+ + \kappa^-$ postulated by Leighton, *et al.*[6] However, some events have been observed recently in which both secondaries are clearly less massive than a κ or τ meson and for which $Q(\pi,\pi)$ is clearly inconsistent with 214 Mev.

The purpose of this paper is to report some cases which are inconsistent with both the $\Lambda^0(p,\pi)$ and $\theta^0[\pi,L,214(\pi,\pi)]$[7] decay schemes. The events have been observed in the 18-inch magnet cloud chambers operating at Mount Wilson (1750-m elevation), the 21-inch magnet cloud chamber operating at Pasadena (220 m), and the 48-inch magnet cloud chambers operating at Pasadena (220 m). The data from the best individual cases will be presented in detail, a summary of the data from a few other cases given, and tentative conclusions drawn from this evidence.

II. MEASUREMENT TECHNIQUE

The curvatures of the tracks were measured by determining coordinates of points on the tracks with a precision comparator and plotting these points on graph paper with the transverse dimension magnified ten times more than the longitudinal dimension. The resulting plots were compared with standard curves to determine the best fit. Angles between tracks were determined by projecting onto a plane at full size and graphically constructing an orthogonal view of the tracks.[6] The calculation of the momentum of a particle included corrections for effects of magnetic-field inhomogeneity and the conical projection involved in the photography. The errors in the momentum measurements were calculated from the estimated maximum detectable momentum in each chamber at the times the photographs were taken.

III. PHOTOGRAPH 8796 (18-INCH MAGNET)

Figure 1 is a reproduction of the first of these unusual V^0 decays observed in this laboratory.[5] The V^0 particle decays in the lower chamber and was undoubtedly produced in the interaction in the lead plate between the two chambers. The energy release calculated assuming the products to be two π mesons is 116 ± 30 Mev. The momentum of the positive particle (curved clockwise) would have to be doubled in order to make the calculated Q value of this event 214 Mev, or to make it consistent with the decay of a Λ^0 particle at

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[1] Thompson, Buskirk, Etter, Karzmark, and Rediker, Phys. Rev. **90**, 1122 (1953); Thompson, Buskirk, Cohn, Karzmark, and Rediker, Report B-2 at Bagnères Conference (unpublished).

[2] Armenteros, Barker, Butler, and Cachon, Phil. Mag. **42**, 1113 (1951); K. H. Barker, Report B-3 at Bagnères Conference (unpublished)

[3] Thompson, Buskirk, Etter, Karzmark, and Rediker, Phys. Rev. **90**, 329 (1953).

[4] Ballam, Harris, Hodson, Rau, Reynolds, Treiman, and Vidale, Phys. Rev. **91**, 1019 (1953); G. T. Reynolds, Report B-5 at Bagnères Conference (unpublished).

[5] Leighton, Wanlass, and Alford, Phys. Rev. **83**, 843 (1951).

[6] Leighton, Wanlass, and Anderson, Phys. Rev. **89**, 148 (1953).

[7] In order to specify concisely what characteristics are assumed when a particular particle is mentioned, the assumed decay products and energy release are stated in brackets or parentheses. For example, the notation $\Lambda^0(p,\pi)$ refers to a class of particles decaying into a proton and π meson only, irrespective of their energy release. The notation $\theta^0[\pi,L,214(\pi,\pi)]$ refers to a class of particles which decay into a π and an L meson (π or μ), whose energy release is calculated as 214 Mev on the assumption that two π mesons are the decay products. The term V particle is used as a general term to include both K mesons and hyperons.

35 Mev. The plane of the decay products contains the interaction in the lead plate within the large errors of measurement introduced by the shortness of the line of flight of the unstable particle. Also the components of the momenta perpendicular to the assumed line of flight of the V^0 particle balance within experimental accuracy. This statement would not be true if the positive momentum were doubled.

IV. PHOTOGRAPH 12590 (21-INCH MAGNET)

Figure 2 shows the decay of a V^0 particle into two light secondaries. On the original film the individual droplets are clearly resolved along all tracks in the chamber.[8] Therefore the relative ionization of the V-particle secondaries and comparison tracks can be determined. If the identity and momenta of the particles producing the comparison tracks are known, then through the application of a theoretical expression for the dependence of ionization on velocity, the specific ionization of the V-particle secondaries can be determined. In the present case the two highly curved comparison tracks are identified as electrons, and the resulting values for the ionizations of the positive and negative secondaries of the V particle are $1.4\pm0.2\times$ minimum and $1.3\pm0.2\times$minimum, respectively. These values are probably too high, since a preliminary study of the ionization of electrons in the velocity range of the comparison tracks has indicated the actual ionization to be somewhat less than that given by the theoretical formula.

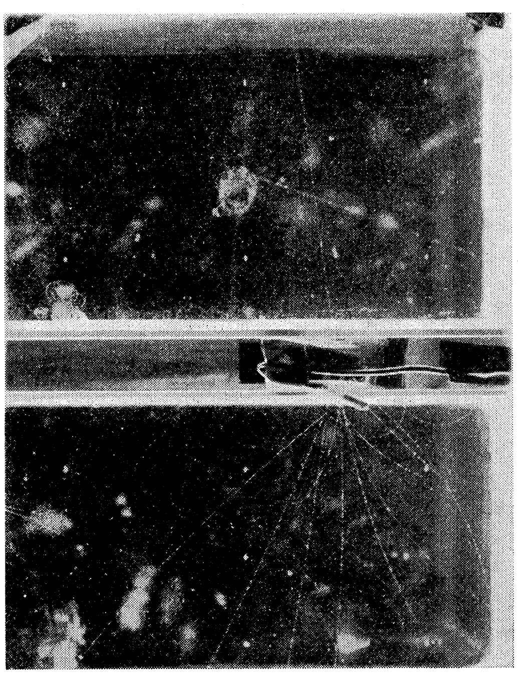

FIG. 1. Photograph 8796 (18-inch magnet). The V^0 decay is observed just below the lead plate. The V^0 particle probably originated at the interaction in the plate. A positive particle corresponds to a clockwise curvature.

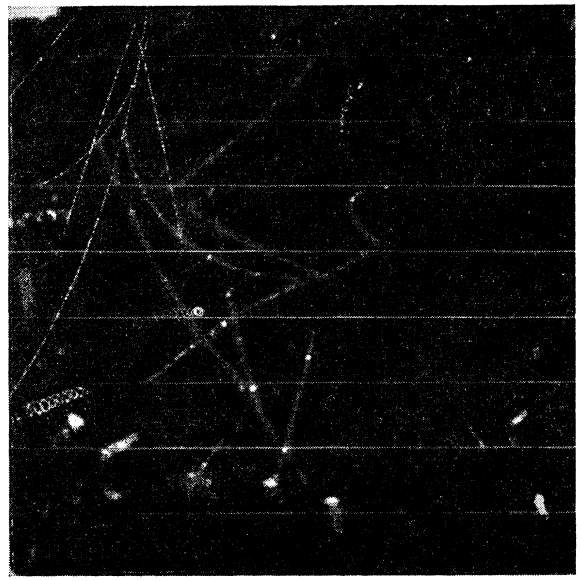

FIG. 2. Photograph 12 590 (21-inch magnet). The V^0 decay is in the upper left corner and the secondaries both leave the chamber through the rear wall. Individual droplets can be counted on the original photograph permitting a comparison of the ionizations of the secondaries and the two curved electron tracks. A negative particle corresponds to a clockwise curvature.

The measured momentum of the negative secondary is 249 ± 12 Mev/c and if it is assumed to be a π or μ meson, its specific ionization is $1.1\times$minimum. If this track is used as a comparison track, the specific ionization of the positive secondary is $1.2\pm0.2\times$minimum. The momentum of the positive track is 493 ± 33 Mev/c. If it is assumed to be a κ meson, its specific ionization is $1.6\times$minimum. Therefore, the present measurements make unlikely the possibility that the secondaries are a π or μ meson and a κ meson, although the possibility that either or both might be *electrons* cannot be excluded from ionization measurements.

The energy release calculated assuming the secondaries to be two π mesons is 79 ± 10 Mev. The short straight track and the longer electron track appear to intersect in the lead above the chamber, although the exact intersection is uncertain because of the large possible multiple scattering of the electron. This possible origin lies in the plane of decay of the V^0 particle and the components of momentum transverse to the assumed lines of flight of the V^0-particle balance within experimental error.

V. PHOTOGRAPH 19143 (48-INCH MAGNET)

Figure 3 shows two decay events which occurred at points A and B in the large upper cloud chamber of the 48-inch magnet. The decay at point A is consistent with the usual θ^0 decay scheme. Its energy release,

[8] E. W. Cowan, Phys. Rev. 94, 161 (1954).

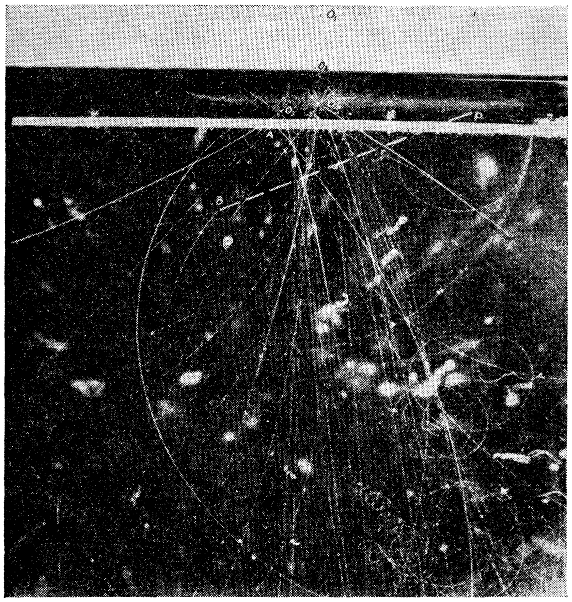

FIG. 3. Photograph 19 143 (48-inch magnet). Two V^0 decays are observed at points A and B. All tracks other than those due to electrons project back to one of the four intersections O_1, O_2, O_3, O_4 in the chamber wall and lead plate. The line PB represents the presumed line of flight of the primary if the decay at point B is a two-body decay.

assuming the products to be two π mesons, is 238 ± 30 Mev.

The decay which appears at point B in this photograph has a Q value of 41 ± 5 Mev, calculated assuming two π mesons as the only decay products. If this event actually represents a two-body decay, momentum balance requires that the point of production of the parent particle lie on the extension of the line BP which lies within the illuminated region of the chamber. Extensions of the lines of flight of all charged particles in the chamber other than electrons and heavily ionizing tracks locate two intersections in the lead plate above the chambers at O_1 and O_2. In addition there are two more nuclear interactions at O_3 and O_4 in the upper chamber wall from which only heavily ionizing tracks emanate. Whereas event A shows good coplanarity and transverse momentum balance if O_2 is assumed to be its origin, it is clear for event B that there is no evidence for any interaction along the extension BP. Furthermore, the locations of the interactions above the chamber indicate that the penetrating shower was probably initiated by a single primary interacting at O_1, with secondaries producing further interactions at O_2, O_3, and O_4. It seems quite improbable that a secondary from one of these events was emitted at nearly 90° to the primary direction, interacted at the right of the lead plate and emitted an energetic unstable particle in a backward direction along the line PB and furthermore produced no charged secondaries which entered the chambers.

We thus conclude that this event is probably not a two-body decay. The possibility that it is a three-body decay will now be considered.

If one assumes the origin of the parent particle to be any of the four observed interactions, the component of momentum of the neutral secondary perpendicular to the primary line of flight lies in the range 170 ± 20 Mev/c to 210 ± 25 Mev/c. This information, together with the assumption of the mass of the neutral secondary, determines a lower limit to the Q value of the three-body decay.

If one assumes the neutral secondary to be a π^0 meson, by analogy with the charged τ-decay scheme, the lower limit on the Q value is 165 ± 20 Mev. The Q value of the *charged* τ meson is known to be 75 ± 1 Mev, and thus the interpretation of this event as a $\tau^0(\pi^0,\pi^+,\pi^-,80)$ decay is inconsistent with the assumption that the particle originated in one of the four observed interactions.

VI. SUMMARY OF CASES

Table I summarizes the important data from the events described and a few others. The ionization of all tracks except those of No. 12 590 were estimated visually.

The three cases that have been added to this tabulation have no clear origin for the parent particle. Nevertheless, the estimated ionizations and the orientations make such possible alternatives as the decay of a $\kappa^\pm$ meson unlikely. Some of these events could also be interpreted as the decay of a neutral particle into a π or μ meson and a κ meson. However, no simplification would result from such an assumption since the best cases cannot be so interpreted.

VII. DISCUSSION

It is tempting to interpret the cases which have a very low Q value as representing the decay of a neutral τ meson into three π mesons. However, it has been shown that such an interpretation is very unlikely for at least one such case (19 143B). In addition there are a number of cases whose two-body Q values are already too high to be interpreted as such a τ^0 decay.

If one wishes to retain the simplifying assumption that most of these cases are decays of the same particle, a scheme with a much higher energy release is required. One possible decay scheme which satisfies this requirement is an alternate mode of decay of the θ^0 particle into $\pi+\mu+\nu$. The computed energy release for this decay is about 244 Mev.

Calculation of the minimum Q value assuming $\theta^0\rightarrow\pi+\mu+\nu$ for case 19 143B yields 245 ± 30 Mev. Thus such an hypothesis would explain all of these unusual cases. It should be pointed out, however, that this decay scheme is certainly not a unique one. For example, another decay scheme which can explain all of these cases is θ^0 or $\tau^0\rightarrow\pi^0+\mu^++\mu^-+(\sim148$ Mev). Both of

TABLE I. Data on unusual V^0 decays.

Event	Secondary	Momentum (Mev/c)	Specific ionization (×minimum)	Mass (units of m_e)	Angle between secondaries	$Q(\pi,\pi)$ (Mev)
8796 (18 in.)	+	570±130	1−1.7	<1200	44°	116±30
	−	120±5	1.5−3	220−420		
56 337 (18 in.)	+	240±65	1−1.7	<600	63°	148±30
	−	390±30	1−1.7	<830		
59 824 (18 in.)	+	124±10	1−2	<310	61°	96±16
	−	365±55	1−1.7	<780		
12 590 (21 in.)	+	493±33	1.4±1.2[a]	840±150[a]	34°	79±10
	−	249±12	1.3±1.2[a]	385±130[a]		
15 329 (48 in.)[b]	+	940±100	1−1.7	<2000	8°	45^{+25}_{-12}
	−	1420±300	1−2	<3500		
19 143 (48 in.)*A*	+	375±30	1−2	<970	46°	238±30
	−	820±70	1−1.7	<1700		
19 143 (48 in.)*B*	+	260±20	1−2	<640	40°	41±5
	−	87±4.5	1.5−3	160−300		

[a] These values are calculated assuming the dubious theoretical electron ionization and are therefore probably too high.
[b] This case is included here because $Q(p,\pi)$ would be 343±80 Mev.

these hypotheses are so broad that they can explain almost any individual event of the type considered here. To confirm or to disprove either of them would require a large amount of accurate data on these rare events.

It is possible that the $\theta^0(\pi,\pi)$ decays having Q values near 214 Mev represent a part of the same three-body decay distribution. However, if this were the case it is unlikely that the observed $Q(\pi,\pi)$ value distribution should be as sharply peaked as present experimental measurements appear to indicate.

VIII. SUMMARY

There is evidence for the existence of a neutral particle which decays into two charged L mesons which cannot be explained by the scheme $\theta^0\rightarrow\pi^+ + \pi^- + (214\text{ Mev})$. If only two-body decays are considered, at least two different new particles have to be postulated with $Q(\pi,\pi)$ near 41 Mev and 90 Mev, respectively, and under this assumption a question as to the point of production in at least one case still remains. Not all of these cases can be explained by the decay of a neutral τ meson into three π mesons. Hence a decay scheme with a higher energy release is indicated. One scheme which might explain these cases in terms of an alternate mode of decay of a known particle is $\theta\rightarrow\pi^\pm + \mu^\mp + \nu + (\sim 244\text{ Mev})$. Of course, many other decay schemes might be postulated, but there is no direct experimental evidence for any particular one of these.

ACKNOWLEDGMENTS

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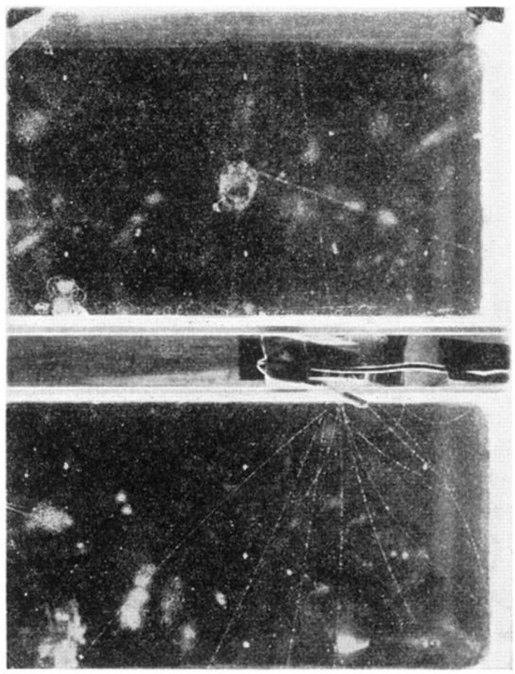

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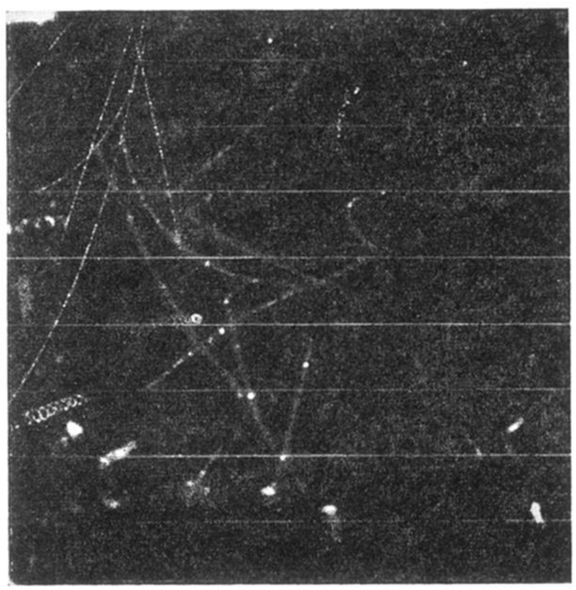

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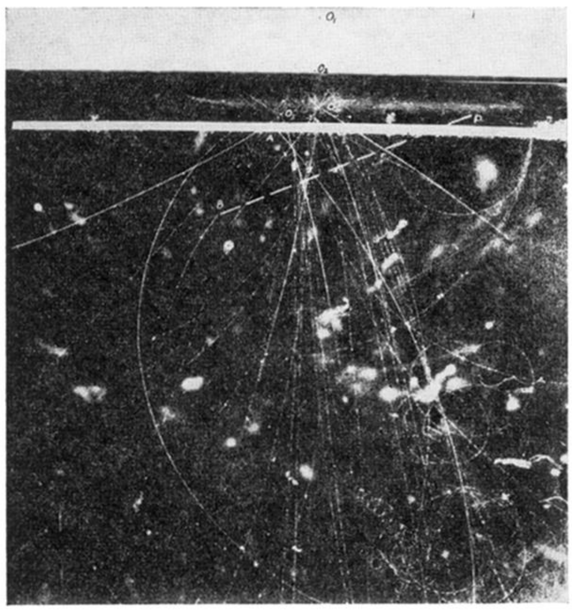

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