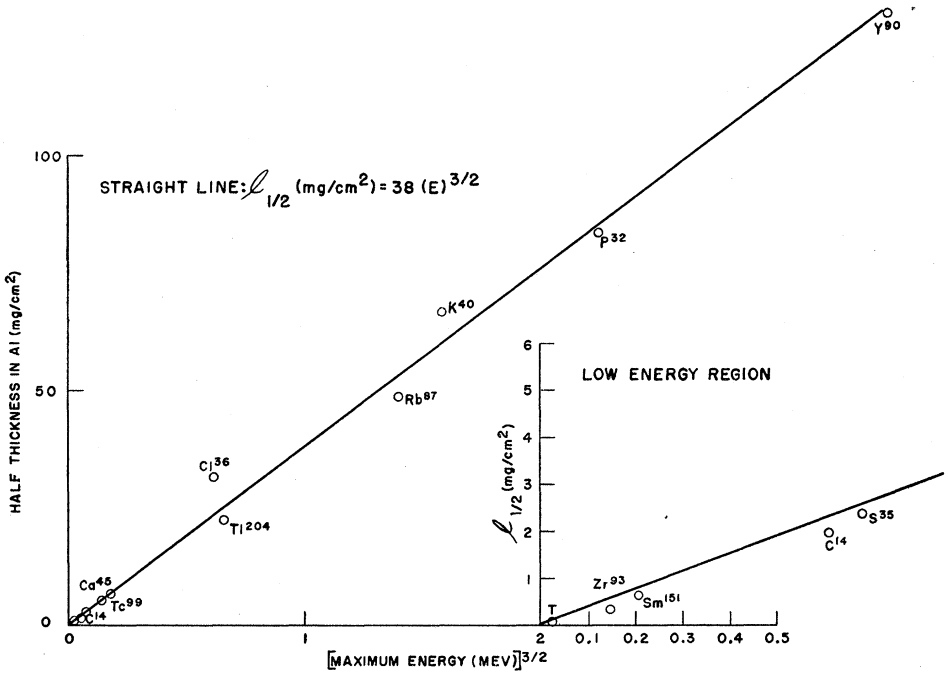

FIG. 1. Relation between half-thickness in aluminum and the $\frac{3}{2}$ power of the maximum beta-ray energy.

detection instruments is exponential for all beta-radioactive isotopes in which single spectra are involved, i.e., a single final state and a single original state—this is so even though the transition may be highly forbidden as in the case of K^{40}. Table I gives data for typical beta-radioactive isotopes of varying characteristics for various absorbers.

It has been discovered that there is a particularly simple relation between the half-thickness in aluminum and the upper energy limit, E, of the beta spectrum involved. This relation is shown graphically in Fig. 1 and is given by the following equation:

$$l_{\frac{1}{2}}(\mathrm{mg/cm^2}) = 38\times(E^{\frac{3}{2}}), \qquad (1)$$

where E is the upper energy limit in Mev.

For other absorber materials the relation of Lerch[3] should be used. It is that the absorption half-thickness is inversely proportional to the expression

$$1+M/100,$$

where M is the mean atomic weight of the absorbing material. The generality of the relation shown in Fig. 1 is considerable. It is to be noted, however, that the most highly forbidden spectra, those of Cl^{36} and K^{40}, deviate somewhat.

It is important to this relation that the sample be placed close to the counter wall and in cylindrical shape with axis in common with that of the counter. It is under these conditions that the absorption curves are exponential and thus yield values of the half-thickness or absorption coefficient. The earlier methods of Feather and Bleuler and Zünti[4] depend on the use of nonexponential absorption curves and the determination of the total range of the radiation. The range-energy relation is more complicated than Eq. (1) which uses the absorption coefficient or half-thickness under conditions of exponential absorption. The dependence of the shape of the absorption curves on the placement of the sample relative to the counter is caused by scattering of the beta radiation.

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Observation of Long-Lived Neutral V Particles*

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THE application of rigorous charge conjugation invariance to strange particle interactions has led to the prediction of rather startling properties for the θ^0-meson state.[1] Some of these are: (I) the existence of a second neutral particle, $\theta_2{}^0$, for which two-pion decay is prohibited; (II) the consequent existence of a second

TABLE I. Data on V^0 events.

Event number	P_+ Mev/c	I_+[a]	P_- Mev/c	I_-[a]	θ[b]	$Q^*_{\pi\pi}$[c] Mev	Comment
1	360 ± 10	<2	206 ± 37	<2	52°	96 ± 17	Not τ^0[d]
2	...		117 ± 50	<2	151°	...	(−) track short
3	>100	<2	>100	<2	140°	...	Both tracks short
4	224 ± 5	<2	58.5 ± 4	<2	91.5°	66 ± 2	Not τ^0; probable e^-
5	147 ± 23	<2	197 ± 6	<2	113.6°	121 ± 12	Not τ^0
6	83 ± 5	<2	137 ± 3	<2	81.0°	40 ± 2	$I_->I_+$, probable $\pi^-\mu^+$, π^-e^+, or μ^-e^+
7	142 ± 13	<2	255 ± 5	<2	124°	163 ± 10	Not τ^0
8	197 ± 25	<2	234 ± 9	<2	97°	147 ± 14	Not τ^0
9	241 ± 33	<2	67 ± 20	<2	142°	109 ± 18	Not τ^0, probable e^-
10	194 ± 8	<2	223 ± 4	<2	140°	140 ± 5	Not τ^0
11	111 ± 4	<2	114 ± 5	<2	77.5°	34 ± 1.4	$I_->I_+$, like No. 6
12	249 ± 5	<2	89 ± 1	2–3	42.0°	38 ± 1.2	Probable π^-
13	290 ± 25	<2	86 ± 25	<2	92°	103 ± 12	μ^- or e^-, ∴ not τ^0
14	183 ± 5	<2	44 ± 5	3–4	102.7	52 ± 2	π^- or μ^-
15	>150	<2	62 ± 7	<2	99°	...	3° deflection in +. $P_{sec}=287\pm30$. Possible $\pi-\mu$ decay. Probable e^-
16	508 ± 18	<2	150 ± 2	<2	65.9°	160 ± 7	Not τ^0, $I_->I_+$
17	136 ± 8	1.5–2	164 ± 5	<2	118.6°	101 ± 5	$I_+>I_-$. Probable π^+, not τ^0
18	251 ± 15	<2	201 ± 50	<2	65.9°	93 ± 15	Not τ^0
19	327 ± 15	<2	112 ± 10	<2	38.3°	51 ± 4	$\pi^+\rightarrow\mu^+$, $P_\mu^*=20\pm10$ Mev
20	167 ± 3	<2	114 ± 3	<2	65.5°	40 ± 2	
21	152 ± 5	<2	120 ± 24	<2	112.5°	79 ± 8	
22	283 ± 10	<2	222 ± 10	<2	50.1°	72 ± 6	Coplanar, $P_\perp=59\pm30$ Mev/c
23	89 ± 1	<2	272 ± 9	<3	128.5°	134 ± 10	Not τ^0

[a] This is a visual estimate of the ionization, in units of minimum ionization as determined from nearby light tracks of $P<50$ Mev/c.
[b] Angle errors have not been computed. An average error of 3° has been used.
[c] $Q^*_{\pi\pi}$ for a normal θ^0 is 214 Mev.
[d] τ^0 is defined as $\rightarrow\pi^++\pi^-+\pi^0$ and is excluded by Q value or transverse momentum.

lifetime, considerably longer than that for two-pion decay of the θ_1^0($\sim1\times10^{-10}$ sec); (III) a complicated time dependence for the nuclear interaction properties.[2] The only additional assumption in this "particle mixture" theory is the nonidentity of θ^0 and its antiparticle.

These theoretical considerations have stimulated us to undertake a search for long-lived neutral particles. To this end, the Columbia 36-in. magnet cloud chamber was exposed to the neutral radiation emitted from a copper target at an angle of 68° to the 3-Bev external proton beam of the Brookhaven Cosmotron.[3] Charged particles are eliminated by the combination of a 4-ft long Pb collimator and a 4×10^5 gauss-inch sweeping magnet. The 6-meter flight path from target to chamber represents $\sim$100 mean lives for the well-known Λ^0 and θ^0 particles which are produced at this energy.[4] To date twenty-six V^0 events have been observed. All of these events have anomalous Q values for two-pion decay, all but one are noncoplanar with the line of flight, and all but one demand at least one neutral secondary to balance transverse momentum.

The cloud chamber operates at a pressure of 0.91 atmos of He and 0.10 atmos of argon. The only additional matter in the direct path of the neutral radiation is the 1-cm thick Lucite chamber wall. A 1.5-in. thick lead filter was placed at the entrance to the collimator to reduce the γ-ray flux reaching the chamber. The aperture (5 in.×1.5 in.) defined a solid angle of 0.002 steradian at 68° to the incident protons. The arrangement yielded readable photographs at a beam intensity of $\sim10^8$ protons per pulse, although the flux through the chamber was estimated to be $\sim10^4$ neutrons. The latter fact points up the virtue of the technique employed.

The relevant primary data on 23 measured V^0 events, found in a run of 1200 pictures, are listed in Table I. We have considered various background effects which could possibly simulate V^0 events:

(1) Production of meson pairs in the gas by neutrons or photons, the nuclear recoil track being too short to observe. However, the number of neutrons above meson production threshold energy at 68° was expected to be quite small. This was verified experimentally by the fact that no negative prongs (i.e., π^- mesons) were observed to emerge from 1218 neutron-induced stars in the gas.

(2) Decay of π^0 mesons, produced in the gas without recoil, into the alternate mode $e^+e^-\gamma$. This is ruled out kinematically for 16 of the events. The argument in (1) also applies.

(3) Production of large-angle electron pairs in the gas by photons.

(4) Bremsstrahlung or scattering of backward-moving particles with consequent large-angle deflections.

These possibilities lead to the prediction of thousands of smaller angle events and to the necessity for large fluxes of backward-moving particles. Neither of these is observed. These arguments will be detailed in a more complete report. They lead to the conclusion that

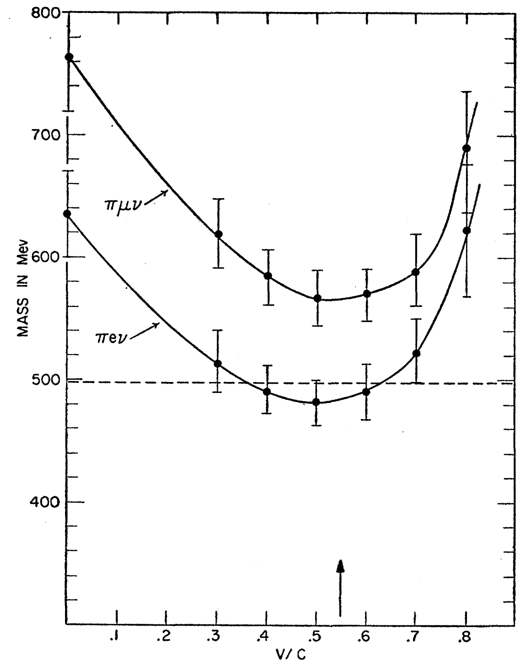

FIG. 1. Average calculated primary mass *vs* velocity of primary particle for assumed decay schemes $\pi^+e^-\nu^0$ and $\pi^+\mu^-\nu^0$. The arrow indicates the peak of the phase space spectra (reference 5). The vertical bars are average deviations of the mean.

the events listed in Table I are indeed examples of the disintegration of a long-lived neutral particle.

A preliminary analysis of the data yields some information on the properties of the new particle.

(1) All but three of the forty-six secondaries are determined to be lighter in mass than the K meson. None can be protons. We have assumed that all are pions, muons, or electrons. The identification of several of the decay products as pions or electrons is indicated in the table.

(2) We have considered various three-body decay schemes, motivated by the observed charged K-meson modes. In Fig. 1, we plot for assumed decay products $\pi^\pm e^\mp\nu^0$ and for $\pi^\pm\mu^\mp\nu^0$, the variation of the average computed mass (15 events were available) of the incoming primary as a function of its assumed velocity. Permutations of the relevant combinations of π's, μ's, e's, and ν's yield similar results. For example $\pi^+\mu^-\nu^0$, $\mu^+\pi^-\nu^0$, $\mu^+e^-\pi^0$, and $\pi^+e^-\pi^0$ are almost coincident. These graphs emphasize the conclusion that the resultant incoming velocity distribution is kinematically sensible only for primary masses near the K mass of 500 Mev.[5] One may also infer that, for a K mass primary, $\pi e\nu$ secondaries are more frequent than $\pi\mu\nu$ or, say, $\mu e\pi$.

(3) All but two of the events are kinematically inconsistent with a Λ^0-mass particle decaying into $\mu^\pm e^\mp N$ or $e^\pm e^\mp N$.[6]

(4) Figure 2 illustrates the detection sensitivity as a function of lifetime for a K-mass particle. Although

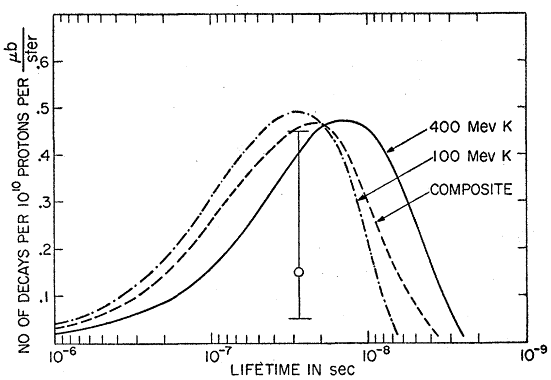

FIG. 2. Detection sensitivity for K mesons as function of lifetime. The composite curve is obtained with the spectra of reference 5. The point indicates the observed yield with a production cross section of $\sim$20 μb/sterad.

the production cross section for K^0 mesons[7] has a large uncertainty, comparison with the observed yield serves to limit the lifetime to the range 10^{-6} sec$>\tau>3\times10^{-9}$ sec. The observed uniform distribution of events in the chamber, together with Fig. 1 also sets a lower limit: $\tau>1\times10^{-9}$ sec. If the lifetime is on the short side of the above interval, then it is likely that many of the anomalous V^0's observed in cosmic rays are examples of this particle, and not alternate decay modes of the θ_1^0.[8]

At the present stage of the investigation one may only conclude that Table I, Fig. 2, and Q^* plots are consistent with a K^0-type particle undergoing three-body decay. In this case the mode $\pi e\nu$ is probably prominent,[9] the mode $\pi\mu\nu$ and perhaps other combinations may exist but are more difficult to establish, and $\pi^+\pi^-\pi^0$ is relatively rare. Although the Gell-Mann-Pais predictions (I) and (II) have been confirmed, long lifetime and "anomalous" decay mode are not sufficient to identify the observed particle with θ_2^0. In particular, a neutral τ meson, if three-pion decay has a small branching ratio, may have these properties. A much stronger test of particle mixtures must await the observation of nuclear interactions or of the striking interference effects which are also predicted by Pais and Piccioni,[2] Treiman and Sachs,[2] and Serber.[10]

The authors are indebted to Professor A. Pais whose elucidation of the theory directly stimulated this research. The effectiveness of Cosmotron staff collaboration is evidenced by the successful coincident operation of six magnets and the Cosmotron with the cloud chamber.

* Supported by the U. S. Atomic Energy Commission and the U. S. Atomic Energy Commission-Office of Naval Research Joint Program.

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Evidence for a Long-Lived Neutral Unstable Particle*

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During a systematic search for K^- mesons in a pellicle stack exposed to a channel of negative particles from the Berkeley Bevatron, four unusual events of the following nature were found: an unstable particle originated in the emulsion from a small star which was produced by a neutral particle. The channel was at 90° to a target bombarded by 6-Bev protons and defined a momentum of 280 Mev/c.

Since the events were of an unusual nature, each one will be described separately.

Event 1.—A $_\Lambda He^4$ hyperfragment originated from a star which also consisted of a π meson of 42±12 Mev, two short recoil tracks, and a proton of 16.6 Mev. The star was produced by a neutral particle. The hyperfragment decayed from rest into a π^- meson, a proton, and a He^3 recoil. The binding of the Λ^0 particle was found to be 1.8±0.6 Mev.[1] A drawing is shown in *A* of Fig. 1.

Event 2.—A negative K meson of 14 Mev was produced in a star which in addition had a low-energy electron and a nucleonic particle of 115 Mev. The K^- meson produced a star from rest consisting of a π meson, a hyperfragment which decayed nonmesonically, and nucleons. The nucleonic particle from the primary star left the stack and therefore the direction of its motion could not be established. However, the kinetic energy of this particle was not sufficient to produce a K^- meson if it were an incident Σ^- or Ξ^- hyperon; therefore we assume that it was an outgoing particle. This event is shown in *B* of Fig. 1.

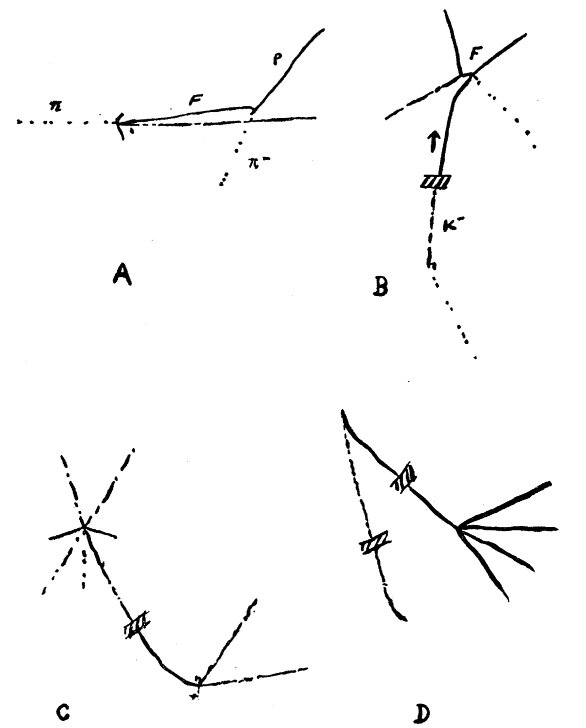

Fig. 1. Drawings of four events which were found in a pellicle stack as shown. A $_\Lambda He$ hyperfragment was produced in *A*, a K^- meson in *B*, probably a Σ^- hyperon in *C*, and a hyperfragment or a Σ^- hyperon in *D*.

Event 3.—A track, 730 microns long, from a seven-pronged star, has a two-pronged star associated with its ending. The primary star was produced by a neutral particle and has a visible kinetic energy of 160 Mev. The connecting particle had a charge of one and appeared to have stopped. The two nuclear particles from the secondary star had a total charge of two or three. In addition there are two tracks of low-energy electrons indicating that the connecting particle was captured. A mass measurement along the connecting track gave $(2200\pm750)m_e$. These facts indicate that the secondary star was produced by a Σ^- hyperon or possibly a Ξ^- hyperon or a K^- meson. A drawing of this event is shown in *C* of Fig. 1.

Event 4.—One particle from a small five-pronged star, which had no incoming particle, appears to have stopped and produced a one-prong star. The prong was most likely due to a proton of 9 Mev. The range of the connecting track is 230 microns. Gap counting showed that the secondary star was not the result of a scattering. Also it is possible to exclude the absorption of a slow π^- meson as its cause. The event is interpreted as a nonmesonic hydrogen hyperfragment decay or the capture of a negative hyperon or K meson. The event is shown in *D* of Fig. 1.

It is very improbable that these four events were produced by fast neutrons since the ratio of these