and we get a positive S_0 in both cases, the two values differing by about 20 percent, but both essentially in agreement with the value given by AOW. It would appear, therefore, that, unless their measurements are greatly in error, their conclusion that liquid He^3 must show a transition below 1°K is correct.

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[1] T. C. Chen and F. London, Phys. Rev. **89**, 1038 (1953) (referred to as CL); see also Weinstock, Abraham, and Osborne, Phys. Rev. **89**, 787 (1953).
[2] Abraham, Osborne, and Weinstock, Phys. Rev. **80**, 366 (1950) (referred to as AOW).

Kinetic Energies of $V_1{}^0$ Particles*

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(Received June 23, 1953)

In the period November 1 to December 11, 1952, 77 V^0 events have been obtained in a cloud chamber[1] operated at the Inter-University High Altitude Laboratory at Echo Lake, Colorado (elevation 10 600 feet).

The purpose of this note is to comment on the remarkably large fraction of the observed V^0 particles having low kinetic energies and to give particulars of two V^0 events which do not fit recently proposed decay schemes.

The cloud chamber operated in an average magnetic field of 5400 gauss and was triggered by a combination of Geiger counters and proportional counters as shown in Fig. 1. A presentation of the production data for the first 49 of these V^0's is given in Table I.

Table I. Summary of cloud-chamber pictures obtained at Echo Lake, Colorado, November 1–December 2, 1952.[a]

	No. of pic- tures	Events with pene- trating showers	No. of penetrating showers from: Air	Central Cu	Top Cu	Pb	Mag- net	Single pene- trating par- ticles	Ran- dom par- ticles or blanks	Elec- tron events
	5122	1149	117	416	395	365	198	1193	1632	1084
No. V^0	49	47	1	18	19	8	1	0	2	0

[a] 1 V^0 per 110 pictures, 1 V^0 per 25 penetrating shower pictures, 1 V^0 per 35 penetrating showers.

Total running time	427 hours.
Time lost in recycling chamber	171 hours.

Approximately three V^0 particles were observed per 24 hours of running time, a rate appreciably higher than reported for previous cloud-chamber investigations performed at similar altitudes.[2–5]

Wherever possible the following measurements were made on the decay products of the V^0 events: (a) momentum, (b) visual estimate of the ionization, (c) total space angle between decay products, (d) angle between each particle and the line of motion of the V^0. As a result, the 77 V^0 particles were classified into three categories:

(1) Those consistent with a decay $V_1{}^0 \rightarrow p + \pi + 39$ Mev.
(2) Those inconsistent with the $V_1{}^0$ scheme (called $V_2{}^0$).
(3) Those for which there is insufficient information for classification in one of the above groups.

Since we consider that any ionization of less than twice minimum is indistinguishable from minimum, the *identified* $V_1{}^0$ particles had momenta below about 0.8 Bev/c. Nevertheless, these low-energy $V_1{}^0$ particles represent an appreciable fraction of all our observed V^0 particles. Table II presents the kinetic-energy data.

Table II. Kinetic energy of $V_1{}^0$ particles.[a]

	Number	Kinetic energy (Mev)	P (Mev/c)
Known $V_1{}^0$	6	30– 70	250– 400
	7	70– 150	400– 600
	6	150– 260	600– 800
	1	260– 380	800–1000
Assumed $V_1{}^0$	20	200– 830	700–1600
	18	200–4000	700–5000
	4	···	Undetermined

[a] Total number of V^0 – 77, number identified $V_1{}^0$ – 20, number V^0 not $V_1{}^0$ – 15, unclassified V_1 – 42.

In this analysis the unknown V^0 particles of group (3) were assumed to be $V_1{}^0$'s. The upper and lower limits of their momenta were calculated from the space angle between the decay products. Table II shows that at least a fraction 20/62, or 32 percent, of the $V_1{}^0$ particles observed in our cloud chamber are produced with kinetic energies below 400 Mev and ~10 percent with kinetic energies below 70 Mev. These percentages can be taken as lower limits since it is likely that not all the unidentified V^0 particles are actually $V_1{}^0$'s. However, because of biases these figures cannot be taken as absolute fractions. The probability that a V particle will decay inside the chamber is proportional to $1\text{-}\exp[-L(P)/Pc\tau_0]$, where P is the momentum of the V particle (in units of Mc), τ_0 is the proper lifetime, and $L(P)$ is a suitably averaged "available" path length in the chamber. The average path length L is expected to be an increasing function of P, since higher-energy particles are more nearly collimated in the vertical direction and are less likely to escape from the sides of the chamber. From the known value of τ_0, and from a consideration of the geometry of our chamber, we estimate that the relative bias against high-momentum V particles is not serious below ~2–3 Bev/c.

Other investigators[3,4,6] also report large fractions of $V_1{}^0$ particles produced with low kinetic energies.

Q values were calculated for five selected $V_1{}^0$ events for which good measurements of the momenta and ionization of both decay products could be made. These values are in agreement with those given by Bridge *et al.*[6] and Armenteros *et al.*[7] However, two events do not seem to fit either the $V_1{}^0$ or $V_4{}^0$ $(\pi^+ + \pi^- + 214\text{ Mev})$[8] decay schemes. The relevant data are given in Table III. There is supporting evidence that the mass and momentum of the positive decay track in event 79–166 are within the stated limits, because the same photograph also contains a positive track of momentum 375 Mev/c and ionization of 3–5 I_{min}, which corresponds to a particle with the mass of a proton. This event cannot therefore be a $V_1{}^0$. In order for it to be a $V_4{}^0$ the positive momentum would have to be increased from 372 Mev/c to 1000 Mev/c.

In event 80–206 the negative decay product penetrated the $1\frac{1}{2}$-in. copper plate in the center of the cloud chamber. Allowing for momentum loss in the copper, we found that its momentum in the upper half of the cloud chamber checks within experimental error with its momentum in the lower half, on the assumption

Table III. Data on two unusual events.

Event No.	Decay products	P (Mev/c)	I/I_{min}	Mass	Angles θ_T	θ_+	θ_-	Q $V_1{}^0$	$V_2{}^0$
79 – 166	Positive	372 ± 100	<2	<1200	36.5				
	Negative	87 ± 15	<3	< 400	±1	···	···	···	66 ± 24
80 – 206	Positive	325 ± 100	<2.5	<1400	32.5	7.5 – 11			
	Negative	262 ± 40	<2	< 800	±1		25 – 21.5	82 ± 24	45 ± 17

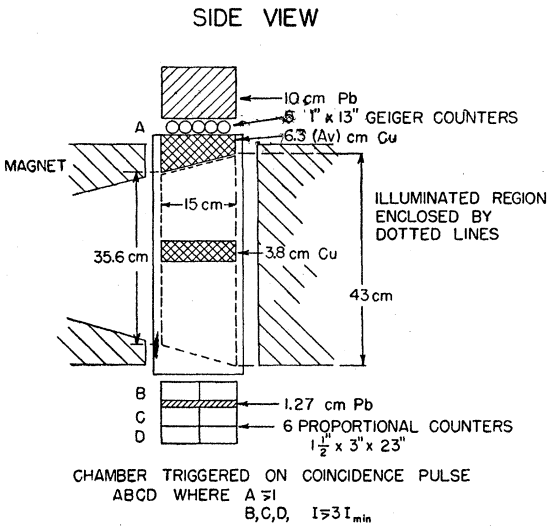

FIG. 1. Experimental arrangement.

that the particle is a π meson. The measurement of the positive momentum is subject to larger errors. However, in order for the event to be consistent with the V_1^0 scheme, the positive momentum would have to be increased to 950 Mev/c and the negative decreased to 220 Mev/c. To fit the V_4^0 scheme the positive momentum must be 1250 Mev/c, and the negative 300 Mev/c.

We are indebted to Dr. R. W. Thompson, Dr. H. S. Bridge, and Dr. C. C. Butler for advance copies of their papers.

[*] Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

[1] Results previously reported at the Cambridge (January 1953) and Washington (May 1953) meetings of the American Physical Society.

[2] Armenteros, Barker, Butler, and Cachon, Phil. Mag. **42**, 1113 (1951).

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

[4] Fretter, May, and Nakada, Phys. Rev. **89**, 168 (1953).

[5] Astbury, Chippindale, Millar, Newth, Page, Rytz, and Sahiar, Phil. Mag. **43**, 1283 (1952).

[6] Bridge, Peyrou, Rossi, and Safford, Phys. Rev. **91**, 362 (1953).

[7] Armenteros, Barker, Butler, Coates, and Sowerby, Phil. Mag. (to be published).

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

The Spectrum and Half-Life of the κ Meson*†

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(Received June 30, 1953)

THE experimental evidence gathered to date indicates[1] that the κ meson has the following mode of decay

$$\kappa^{\pm}\rightarrow\mu^{\pm}+2\nu. \qquad (1)$$

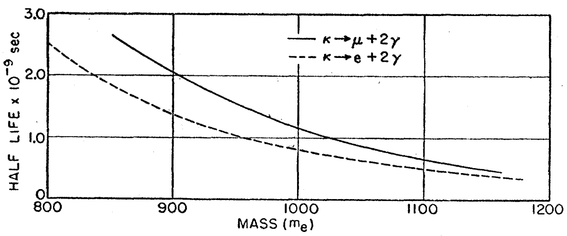

FIG. 1. The variation of half-life of the κ meson is plotted against its mass in units of the electron mass. The solid curve is for decay into a μ meson and two neutrinos while the dashed curve is for decay into an electron and two neutrinos.

Michel[2] has discussed the general problem of the interaction between four Dirac particles and applied this to the decay of the μ meson. Before one can apply these considerations directly to the κ-meson decay some decision as to the nature and size of the interaction constant must be made. In a recent paper Peaslee[3] has concluded from studies of beta decay that the correct interaction is $(S\pm T+P)$, where the ± refers to $\beta^{\pm}$ emission. If the same linear combination is assumed for μ-meson decay, the coupling constant for this process is identical with that obtained from beta decay,

$$|f_1|=1.44\pm0.04\times10^{-49}\ \text{erg cm}^3. \qquad (2)$$

Applying the transformation (67) of reference three to the spectrum formula (45) of reference two, one obtains

$$P(E)dE=\frac{8(E^2-\mu^2)^{\frac{1}{2}}}{3\hbar(2\pi\hbar^2c^2)^3}\{3E(W-E)f^2+(E^3-\mu^2)(f_3^2+f_4^2+2f_5^2)$$
$$+3\mu(W-E)(f_3^2-f_4^2+f_1f_2)\}dE, \qquad (3)$$

where κ and μ are the rest energies of the κ and μ mesons, respectively, f^2 is the sum of the squares of the coupling constants, and the range of E is $\mu\leq E\leq W=(\kappa^2+\mu^2)/2\kappa$.

If one now assumes that the linear combination for κ-meson decay is the same as that for μ-meson and beta decay, then the only f_i not zero is f_1 and the half-life and decay spectra are immediately determined. Further, since the experimental evidence does not rule out the mode of decay,

$$\kappa^{\pm}\rightarrow e^{\pm}+2\nu, \qquad (4)$$

the above remarks can be applied to this also.

The variation of half-life with rest mass is plotted in Fig. 1 for both modes of decay. It is seen that for the present best estimate of the rest mass[1] ($\kappa=940m_e$) the decay into an electron and two neutrinos is some 40 percent more rapid than the decay into a μ meson and two neutrinos. One would thus expect roughly equal numbers of $\kappa\rightarrow e+2\nu$ and $\kappa\rightarrow\mu+2\nu$ decays from half-life considerations. The half-life of the $\kappa\rightarrow\mu+2\nu$ mode associated with a rest mass of 940 m_e is 1.63×10^{-9} second, which is in agreement with recent work by Alford and Leighton.[4]

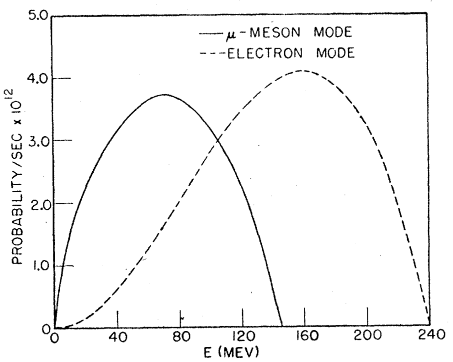

FIG. 2. The spectrum of the charged decay particle for the κ-meson decay. The κ-meson rest mass was taken to be 940 m_e. The solid curve is for decay into a μ meson and two neutrinos, while the dashed curve is for decay into an electron and two neutrinos.

In Fig. 2 the spectrum of the decay particle is plotted for both modes of decay using 940 m_e for the κ rest mass. The end point for the $\kappa\rightarrow\mu+2\nu$ decay is 145 Mev while that for the $\kappa\rightarrow e+2\nu$ mode is 240 Mev.

From these considerations it would seem fruitful to investigate further the energy distribution of the decay products of the meson. From Fig. 2 one would expect two distributions (if both modes of decay exist), the electron distribution being the more asymmetric with the bulk of the decay electrons having high energies. Since almost twice as much energy is available to the electron, this mode of decay, if it exists, should be readily apparent. Probably the best method of identifying the $\kappa-\mu$ decay