vide more electrons for Auger hyperfine transitions and thus increase the depolarization.[2]

A run was also made with lithium fluoride as a target in a field of 2.0 ± 0.1 kG. About 500 000 decay electrons were analyzed. A substantial number of muons stop in the lithium (25% according to the Z law) which has a spin of $\frac{3}{2}$. However, the hyperfine state with spin 2 has a much lower precession frequency than the range we are examining, and the state with spin 1 is almost entirely depolarized. Hence muons stopping in the lithium do not confuse our results, but only add some background.

The frequency spectrum for LiF is given in Fig. 3(c). A 3-μsec acceptance gate for electrons was used. The negative muon lifetime in F is about 1.5 μsec. There does not seem to be any evidence for precession at the expected frequency of about 10 Mc/sec.

To see if there is any precession at early times which might not show up in the analysis of all the data, the first 0.5 μsec of data was reanalyzed giving the spectrum in Fig. 3(d). As a comparison, the second 0.5 μsec was also reanalyzed and is shown in Fig. 3(e). Since the first 0.5 μsec had about 200 000 events, the noise level should be $(500\,000/200\,000)^{1/2}$, ~1.6 times higher than in Fig. 3(c). The second 0.5-μsec interval had 130 000 events, and so the noise level should be $(500\,000/130\,000)^{1/2}$, ~2 times higher.

From examining Fig. 3(c), (d), and (e), one may conclude that for the first 0.5 μsec there are peaks at 10 Mc/sec and 20 Mc/sec that are slightly above the expected noise. A precession at 10 Mc/sec, disappearing after 0.5 μsec, is consistent with the results of Culligan *et al.* The peak at 20 Mc/sec, if real, is hard to understand. We have no ready explanation for it.

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[1] R. Winston and V. L. Telegdi, Phys. Rev. Letters 7, 104 (1961).

[2] L. V. Egorov, A. E. Ignatenko, and D. Chultem, J. Exptl. Theoret. Phys. (U.S.S.R.) 37, 1517 (1959) [translation: Soviet Phys.–JETP 37 (10), 1077 (1960)].

[3] G. Culligan, J. F. Lathrop, V. L. Telegdi, and R. Winston, Phys. Rev. Letters 7, 458 (1961).

[4] D. P. Hutchinson, J. Menes, G. Shapiro, A. M. Patlach, and S. Penman, Phys. Rev. Letters 7, 129 (1961).

MUONIC Λ^0 DECAY*

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We have recently observed a clear-cut example of the decay $\Lambda^0 \rightarrow p^+ + \mu^- + \bar{\nu}$. The probability of any other interpretation being correct is very low.

It is generally difficult to distinguish an apparent muonic Λ decay unambiguously from the decay sequence $\Lambda^0 \rightarrow p + \pi^-$, $\pi^- \rightarrow \mu^- + \bar{\nu}$, with the π decaying close to its origin. A previously reported event[1] possessed an ~10^{-2} over-all probability against this interpretation[2]; however, the event described herein is completely free of this particular ambiguity and is therefore of importance in establishing this decay mode.

Our event was observed in an exposure of the Alvarez 72-in. hydrogen bubble chamber to a beam of 1.12-BeV/c π^- mesons. The Λ^0 is produced in association with a K^0 meson which decays via $\pi^+\pi^-$. This enables one to fit the event unambiguously. The measurement of all the tracks was done on a digitized microscope with three views accessible, and the event was fitted by the least squares kinematic program KICK.

The $\Lambda^0 K^0$ production occurs at A (see Fig. 1). The K^0 travels 1.01 cm (0.26 lifetimes) and then decays into $\pi^+\pi^-$ at B. The K^0 is consistent only with production in association with a Λ^0 and predicts a Λ^0 in the direction of the neutral measured track for the Λ^0. This gives an accurate determination of the Λ^0 momentum and certifies its origin. The Λ^0 travels 3.76 cm (0.92 lifetimes) before decaying at C. The only decay hypothesis which fits

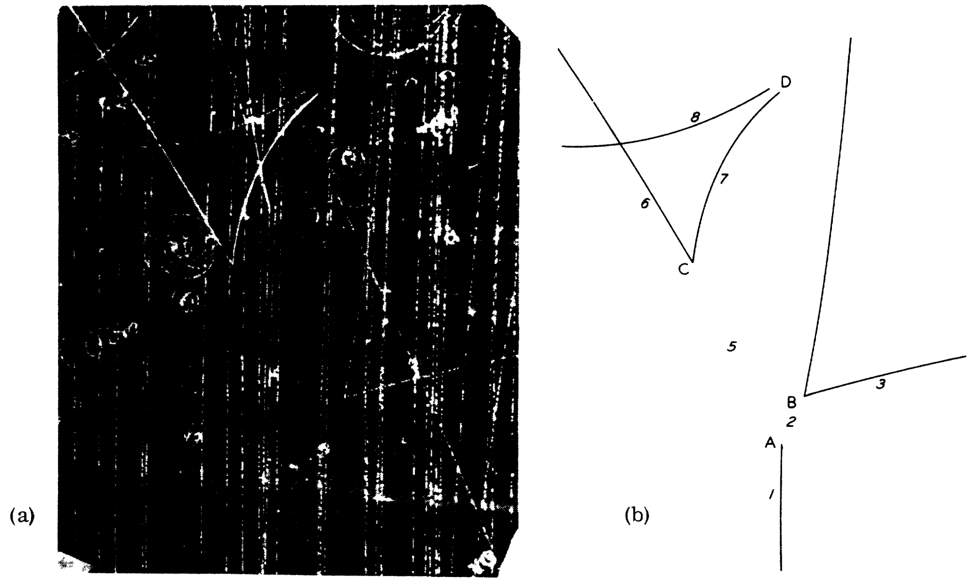

FIG. 1. (a) Picture of event. (b) Tracing of picture. Track identification: 1, incoming π^- beam; 2, K zero; 3, π^-; 4, π^+; 5, lambda; 6, proton; 7, μ^-; and 8, electron.

is $\Lambda^0 \to p^+ + \mu^- + \bar{\nu}$, which fits very well. (See Table I for fit.)

Furthermore, the negative track of the Λ goes 3.94 cm before stopping and is identified as a μ from its curvature. This is confirmed by the associated electron near the track end D, and hence the decay $\Lambda^0 \to p + \pi^- + \gamma$ (inner bremsstrahlung) is ruled out. The fact that the electron is not directly attached to the μ is explained in terms of D_2 in the chamber; this is a common occurrence for stopping μ^-.[3]

The possibility of $\Lambda^0 \to p + \pi^-$, $\pi^- \to \mu^- + \bar{\nu}$ is ruled out for this event on the following basis: Using the Λ^0 direction and momentum along with the proton direction and momentum, a one-constraint fit can be made for $\Lambda^0 \to p + \pi^-$ which will predict the desired π^- direction and momentum. The π momentum thus predicted is 58.7 ± 3.8 MeV/c. Its direc-

Table I. Summary of measured and fitted data.

Particle	Track No.	Length (cm)	Azimuth	Dip	Momentum (MeV/c)
			Measured		
π^-	1	39.43	93.86 ±0.10	1.29 ±0.26	1114.5 ±11
K^0	2	1.01	72.30 ±0.65	-2.59 ±3.60	641.1 ± 3.6[a]
π^-	3	24.36	20.09 ±0.28	-36.67 ±0.33	209.6 ± 4.2
π^+	4	44.53	85.58 ±0.11	1.93 ±0.28	550.0 ± 5.5
Λ^0	5	3.76	117.31 ±0.15	11.51 ±0.47	610.8 ± 4.5[b]
p	6	9.26	122.48 ±0.27	9.40 ±0.33	578.0 ±69.4
μ^-	7	3.94	84.83 ±1.44	17.92 ±1.96	42.45[c]
			Fitted with one constraint, $\chi^2 = 0.1165$		
Λ^0	5		117.31 ±0.15	11.50 ±0.47	610.8 ± 4.5
p	6		122.48 ±0.27	9.40 ±0.33	601.8 ± 4.3
μ	7		84.83 ±1.44	17.92 ±1.99	42.45 ± 0.5
ν	31		347.16 ±5.05	14.12 ±8.67	43.0 ± 1.6

[a] Fitted values.
[b] Fitted from K^0 fit and Λ^0 direction.
[c] Measured by range.

tion, however, is 56.5° ± 2.9° from the measured direction of the negative track. This is a 9 standard deviation discrepancy from any possible fit, regardless of how soon the decay took place.

There is one other decay sequence that can be considered as a possible interpretation of any apparent muonic Λ decay, and that is $\Lambda^0 \rightarrow p+\pi^- +\gamma$, $\pi^- \rightarrow \mu^- + \bar{\nu}$. The probability of $\Lambda^0 \rightarrow p+\pi^- +\gamma$ (inner bremsstrahlung) has been calculated by Barshay and Behrends as a function of proton momentum.[4] The greatest probability of $\Lambda^0 \rightarrow p+\pi^- +\gamma$ decay into a π^- consistent with the measured μ^- of our event is 6×10^{-3}. To be undetectable visually the π^- must decay into the μ^- within 1 mm of its origin. The chance of this occurring is 4×10^{-4}. Furthermore, such a decay sequence requires the γ and ν to come off nearly colinear if the resulting p, μ^-, and $\gamma+\nu$ are to fit muonic Λ decay. This gives a combined probability of chance occurrence of $\sim10^{-6}$.

Since our example comes from 2500 Λ, the overall probability of chance occurrence is $\sim2.5\times10^{-3}$. Therefore, this interpretation cannot be completely ruled out. However, the combined probability of neither of the two thus far reported events being muonic Λ^0 decay is $\sim10^{-4}$. Thus with this additional event the muonic Λ decay is established to fairly convincing odds.

Inasmuch as the majority of the true Λ - μ decays cannot be separated unambiguously from $\Lambda^0 \rightarrow p+\pi^-$, $\pi^- \rightarrow \mu^- + \bar{\nu}$, this single event may represent several other true Λ - μ decays. Theory predicts the rate of muonic Λ decays as 0.3% and for electronic Λ decays as 1.6%,[5] with a ratio of μ's to electrons of 0.17. It is known that the experimental electronic rate[6] $[(0.9\pm0.2)\times10^{-3}]$ is about one order of magnitude lower than that predicted by theory, but it is not known whether or not the muonic decay rate is down by the same factor. With one certain event in a sample of 2500, one can at best say that the Λ muonic decay rate is not inconsistent with either hypothesis.

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[1] F. Eisler, J. M. Gaillard, J. Keren, M. Schwartz, and S. Wolf, Phys. Rev. Letters 7, 136 (1961).

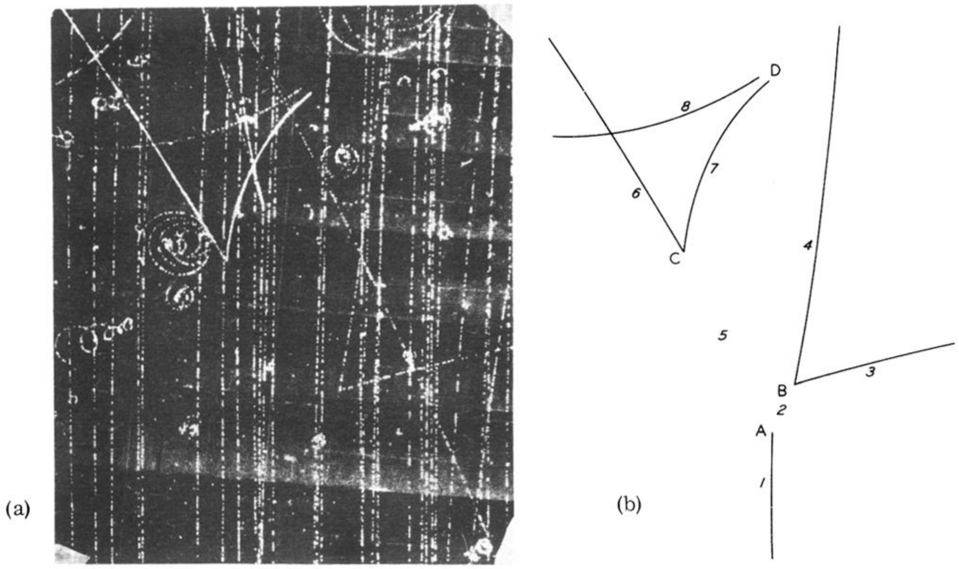
[2] The authors reported a less than 10^{-5} odds against the $\Lambda^0 \rightarrow p+\pi^-$, $\pi^- \rightarrow \mu^- + \bar{\nu}$ decay sequence. Since over 10^3 lambdas had been analyzed, the over-all probability is $\sim10^{-2}$.

[3] The mean of the gap length between a stopping μ^- track and the beginning of the associated decay electron depends on the deuterium concentration in the chamber, which in turn depends on the hydrogen purification cycle used in filling the chamber [R. H. Hildebrand (private communication)]. M. Cresti *et al.* [University of California Laboratory Report UCRL 3782 (unpublished)] list 0.6 mm as the mean gap length in the Berkeley 15-in. chamber. Hildebrand gives 2.0 mm for the mean gap in H_2 with ~5 parts per million D_2. The gap in our event is 2.0 mm.

[4] S. Barshay and R. E. Behrends, Phys. Rev. 114, 931 (1959).

[5] R. P. Feynmann and M. Gell-Mann, Phys. Rev. 109, 193 (1958).

[6] William E. Humphrey, J. Kirz, Arthur H. Rosenfeld, J. Leitner, and Y. I. Rhee, Phys. Rev. Letters 6, 478 (1961).



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