ilar experiment carried out at the Departement de Physique Nucléaire in Strasbourg, France, arrived when this report had already been prepared. The results seem to be in qualitative agreement with those presented here.

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[17]W. Forsling (private communication).

EVIDENCE FOR LOW RATES FOR β DECAY OF Σ^- AND Λ HYPERONS*

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(Received April 6, 1961)

According to the theory by which strangeness-nonconserving Fermi interactions take place with the same coupling constant as strangeness-conserving weak interactions,[1] the hyperon decays,

$$\Sigma^- \rightarrow e^- + n + \bar{\nu} \quad (1a)$$

and

$$\Lambda \rightarrow e^- + p + \bar{\nu}, \quad (1b)$$

were expected to occur with branching fractions of 5.6% and 1.6%, respectively, with electron spectra rather close to phase space. Actually, experimental rates are already known to fall below these rates by about an order of magnitude,[2,3] and these data are further substantiated in this Letter.

The muonic decays $\Sigma^- \rightarrow \mu^- + n + \bar{\nu}$ and $\Lambda \rightarrow \mu^- + p + \bar{\nu}$ were expected with branching fractions of 2.5% and 0.3%, respectively, and are probably also lower by a factor of ten or more. These rare muonic decays are hard to separate from background, especially from normal pionic sigma decay followed by pion decay in flight; accordingly we shall not discuss muonic decay in this Letter.

The strangeness-conserving beta decay,

$$\Sigma^- \rightarrow e^- + \Lambda + \bar{\nu}, \quad (2)$$

is still expected to occur with a branching fraction of 2×10^{-4}.[4] The beta decay of Σ^+,

$$\Sigma^+ \rightarrow e^+ + n + \nu, \quad (1c)$$

is inhibited by the proposed $\Delta S/\Delta Q = +1$ rule.

Our $\Sigma^\pm$ and Λ particles were produced in the Berkeley 15-inch hydrogen bubble chamber by the reactions

$$K^- + p \rightarrow \Sigma^\pm + \pi^\mp, \quad (3)$$

$$K^- + p \rightarrow \Lambda + \pi^0, \quad (4)$$

$$K^- + p \rightarrow \Sigma^0 + \pi^0, \quad \Sigma^0 \rightarrow \Lambda + \gamma, \quad (4a)$$

where the K^- is captured at rest or interacts at very low energy. In order to be able to separate some of the β decays of Σ from the dominant pionic modes

$$\Sigma^\pm \rightarrow \pi^\pm + n, \quad (5)$$

we used the criterion that the visible decay particle (the electron candidate) should have a laboratory momentum $p \leq 100$ Mev/c,[3] and a track length ≥ 5 cm to assure reliable momentum measurements.

In order to eliminate two major sources of background we did not include in the sample Σ^- particles, which left either a very short or a very long track in the chamber.

(a) When a zero-length Σ^- undergoes β decay, the e^- could be confused with the e^- of the electron pair from the chain

$$K^- + p \rightarrow \Lambda + \pi^0, \quad \pi^0 \rightarrow e^+ + e^- + \gamma, \quad (6)$$

where $p(e^+)$ is close to that of the π^+ of Reaction (3). Similarly, Σ^+ of range < 1 mm were excluded.

(b) When a Σ^- undergoes β decay very near the end of its range, the e^- can be confused with a very close Compton electron from the chain initiated by Σ^- capture,

$$\Sigma^- + p \rightarrow \Sigma^0 + n; \quad \Sigma^0 \rightarrow \gamma + \Lambda; \quad \gamma \rightarrow \text{Compton}. \quad (7)$$

The decay mode

$$\Sigma^+ \to p + \pi^0 \quad (8)$$

(where the proton track can be readily identified by ionization and range) was not examined. Its contribution to the branching fraction was taken into account, however.

Most of our Σ events were obtained with the 1960 K^- beam.[5] About 60 000 K^- particles (at approximately 2 per picture for 2×10^{11} protons per pulse) entered the chamber, with an average $p \approx 230$ Mev/c. These yielded 6700 Σ^- decays and 1500 Σ^+ decays through Channel (5), which satisfied the above criteria, and were also flat enough (dip ≤ 45 deg) to permit preselection on scanning projectors. Momentum templates and correction tables for dip, magnification, and similar effects were used to select the sample to be measured. The efficiency of this process is close to 100% at low electron momenta, but losses near 100 Mev/c reduce the over-all efficiency to about 85%.

In addition to this, a 1958 K^- experiment produced 1400 Σ^- decays and 300 Σ^+ decays through Channel (5) which satisfy our selection criteria.[6]

All these events have been measured; therefore, the efficiency for the search is close to 100%.

If we combine the efficiency with the fraction of the phase space for $0 \leq p_e \leq 100$ Mev/c (which is about 1/3), the effective branching-fraction denominator becomes $\frac{1}{3}(0.85\times6700+1400)=2400$ for Σ^-, and $\frac{1}{3}(0.85\times1500+300)=525$ for Σ^+ through Channel (5). If we include the Σ^+ decays through Channel (8), our effective denominator becomes 1050 for Σ^+.

Two further sources of background were considered:

(a) About 1 in 300 Σ^- particles interacts in flight, and by Process (7) or similar means produces an e^- within 5 mm. The probability for this is less than 10^{-6} if we exclude the cases in which a visible Λ decay makes the reaction easily detectable.

(b) If the chamber is not operating at optimum sensitivity, pions and muons with $p \approx 100$ Mev/c can be close to minimum-ionizing. Then, if the decay electron is not identified by range or delta rays, the decay modes,

$$\Sigma^\pm \to \pi^\pm + n + \gamma \quad (9)$$

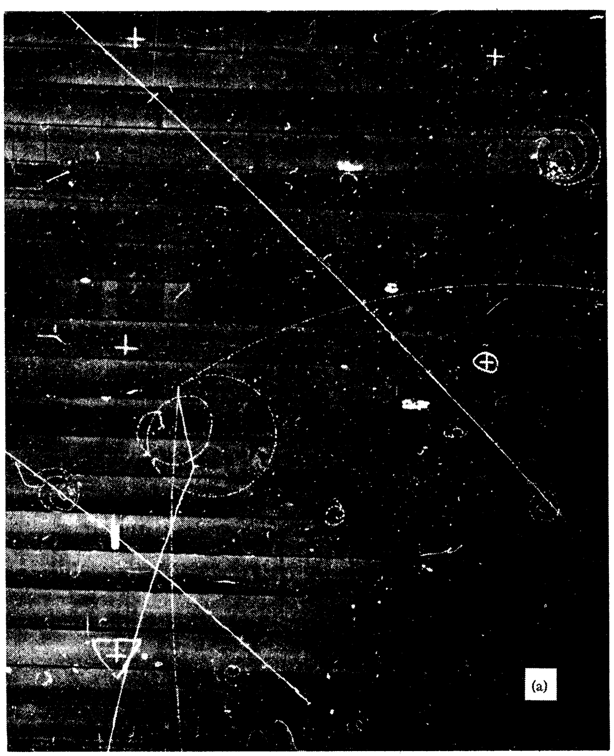
and

$$\Sigma^\pm \to \pi^\pm + n \text{ followed by } \pi^\pm \to \mu^\pm + \nu \quad (10)$$

within a few millimeters, could simulate β decay with a small probability.

The results of our search are as follows:

We found three Σ^- decays which had charged decay particles with $p < 100$ Mev/c. One of these has a decay track of 91 ± 3 Mev/c, and could be a background event of the second type mentioned above, since the ionization does not rule out particles heavier than an electron. The second one is shown in Fig. 1; it has a decay electron



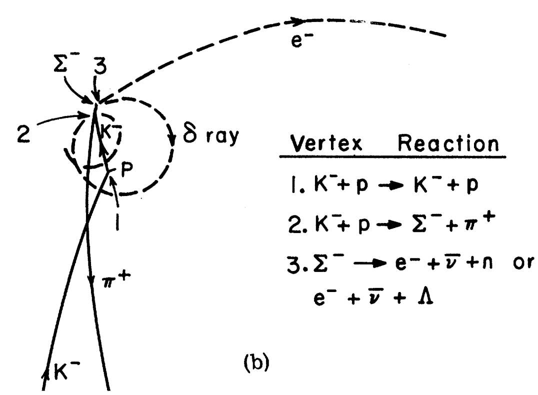


FIG 1. β decay of Σ^- produced in the reaction $K^-+p\to\Sigma^-+\pi^+$ [(a) bubble chamber photograph; (b) diagram]. The K^- particle scatters elastically before being captured. A δ ray of 5 Mev/c originates from the first 2.5 mm of the decay track. The momentum beyond the δ ray was measured as 43 ± 1.2 Mev/c. The length of the Σ^- track (2.2 ± 0.3 mm) indicates that the Σ^- did not stop before decay.

of 49 ± 2 Mev/c, and is therefore either a strangeness-nonconserving β decay (1a) or a strangeness-conserving β decay (2). The third candidate has a decay electron of 93 ± 5 Mev/c. This event could, however, be due to Chain (6), because the π^+ from Reaction (5) doubles back on the incoming K^- track, thereby obscuring the Σ^- production vertex.

No candidates for Σ^+ β decay were found.

Next we discuss the 900 visible Λ decays produced by the 1958 K^- beam. These were measured, and the ones that did not fit the kinematics for pionic decay were examined for coplanarity. Other than one event found by inspection,[7] no certain β decays were found.

Our efficiency for finding Λ β decays is about 70%. Therefore, the effective denominator (including the unseen $\Lambda \rightarrow n + \pi^0$ decays) is $(\frac{3}{2})900 \times 0.70 = 950$.

Our current information on β branching fractions is summarized in Table 1. The branching fractions calculated from this table are little more than lower limits. For every sure leptonic decay there are usually several "possibles." It might be reasonable to double these fractions, yielding 1/1000 $\Sigma^- \rightarrow e^-$; 0/1000 $\Sigma^+ \rightarrow e^+$; and 2/1000 $\Lambda \rightarrow e^-$. This guess should then be credible within a factor of 2, again assuming that the electron spectrum does not deviate drastically from phase space.

Table I. Accumulated information on β branching fractions.

	Effective denominator			Numerator (β decays)		
	Σ^-	Σ^+	Λ	Σ^-	Σ^+	Λ
World survey of events reported up to November, 1958[a]	200	100	1500	1[b]		2
Dyer[c]	67	130	···	0	0	···
Berkeley propane bubble chamber[d]	2000	2000	10 000	1?	0	5
Baglin et al. (Freon chamber)[e]	150	···	4500	0	···	≈8
Helium chamber[f]	60	70	···	0	0	···
Franzini and Steinberger (propane chamber)[g]	···	···	···	1	···	···
This Letter	2400	1050	950	1+2?	0	0
Total	4900	3350	17 000	$2+n$?	0	15

[a]See reference 7.

[b]J. Hornbostel and E. O. Salant, Phys. Rev. 102, 502 (1956). In this experiment only five normal Σ decays were found, and no detection efficiency for β decays was reported. The event listed is a probable β decay of a Σ particle of undetermined charge.

[c]John N. Dyer, thesis, University of California Radiation Laboratory Report UCRL-9450, November, 1960 (unpublished).

[d]Wilson M. Powell, Lawrence Radiation Laboratory (private communication). The Powell group did not scan specially for β decays. However, bremsstrahlung and curling up make a large fraction of the electrons easy to spot. The 2000 Σ^- and Σ^+ represent approximately 1/3 of the propane group's sample (we assume they also have a 1/3 probability of finding the β decay of a Σ). The possible $\Sigma^- \rightarrow e^- + n + \bar{\nu}$ decay could also be the decay of a K meson, since Σ production did not have an associated pion. The 10 000 Λ's represent about 1/2 of the group's sample of 14 000 corrected for the unseen $\pi^0 + n$ decays. The factor of 1/2 assumes that they can identify electrons below 85 Mev/c.

[e]P. Falk-Vairant, postdeadline paper, presented at the meeting of the American Physical Society, Berkeley, December 29-31, 1960. Our numbers come from a later Letter from Frank T. Solmitz from École Polytechnique on January 13, 1961.

[f]Martin M. Block, Duke University (private communication).

[g]P. Franzini and J. Steinberger, Phys. Rev. Letters 6, 281 (1961). This event is definitely a strangeness-nonconserving decay (1a). The e^- momentum rules out the possibility of $\Sigma^- \rightarrow \Lambda + e^- + \bar{\nu}$.

If we compare this with the original predictions by Feynman and Gell-Mann,[1] we have:

	Experiment	Theory
$\Sigma^- \to e^- + n + \bar{\nu}$	≈0.1%	5.6%
$\Lambda \to e^- + p + \bar{\nu}$	≈0.2%	1.6%
$\Sigma^+ \to e^+ + n + \bar{\nu}$	≈ 0	0

The discrepancy is about 10 to 1 for Λ decay and perhaps more for Σ decay; we conclude that β decays of hyperons cannot be explained by forms of Fermi interaction such as that of Feynman and Gell-Mann having the same coupling constant at each permitted vertex.

We wish to thank Dr. Donald H. Miller and Dr. Ronald R. Ross for valuable discussions and suggestions. The efficient work of our scanners, especially David J. Church and Lawrence A. Drews, is greatly appreciated.

*Work done under the auspices of the U. S. Atomic Energy Commission and the Office of Naval Research.

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

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[3]J. Leitner, P. Nordin, A. H. Rosenfeld, F. T. Solmitz, and R. D. Tripp, Phys. Rev. Letters 3, 186 (1959).

[4]Note that for 1/3 of these decays the Λ will subsequently decay via its neutral channel, and the over-all event then becomes indistinguishable from the low-energy electron cases of reaction (1a).

[5]Pierre Bastien, Orin Dahl, Joseph J. Murray, Mason Watson, Ray G. Ammar, and Peter Schlein, in Proceedings of the 1960 International Conference on Instrumentation for High-Energy Physics (Interscience Publishers, Inc., New York, 1961), p. 299.

[6]Some of the events included in this sample have already been reported in reference 3.

[7]P. Nordin, J. Orear, L. Reed, A. H. Rosenfeld, F. T. Solmitz, H. D. Taft, and R. D. Tripp, Phys. Rev. Letters 1, 380 (1958). The survey in that paper did not include the Λ denominator we are now reporting, although it did include the one β decay in the numerator.

π^--p ELASTIC SCATTERING AT 550, 600, 720, 900, AND 1020 Mev

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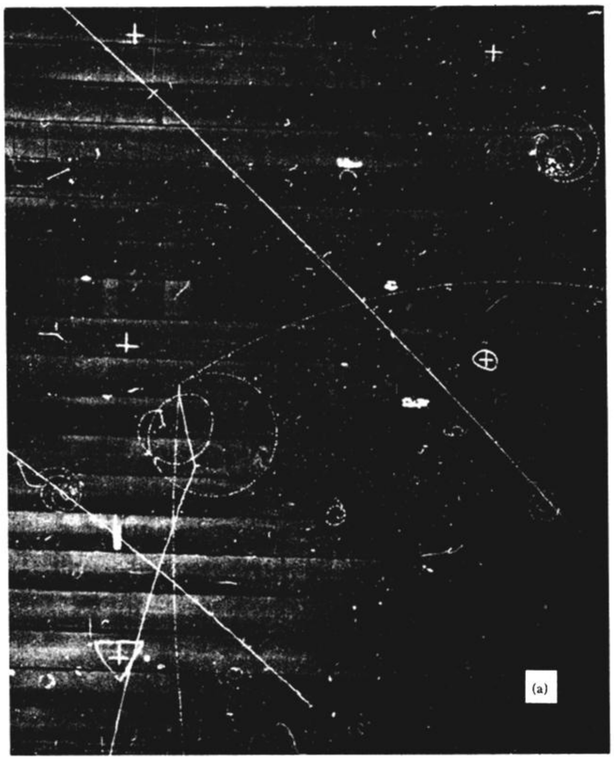
This Letter contains the results of measurements of differential cross sections taken in the energy region of the second and third peaks of the π^--p total scattering cross section.[1,2] The data were obtained by using an array of recoil proton scintillation counters in coincidence with pion detectors to identify elastic events. Details of the experimental procedure and the data analysis will be published separately.[3]

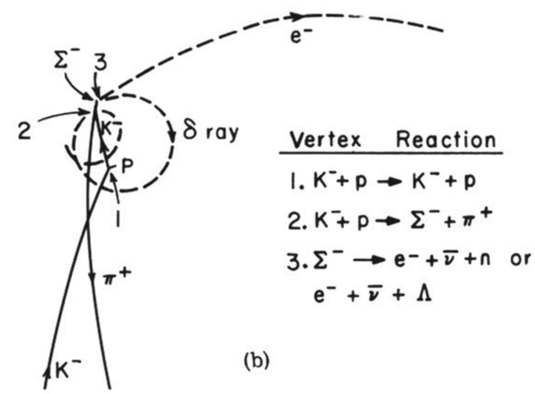
It should be here stated that we were unable to arrive at an independent normalization for the data, because of pion beam monitoring difficulties, although the shapes of the curves were rather well determined and repeatable. Therefore, we normalized our data to the total elastic cross sections as determined by other workers and summarized by Falk-Vairant and Valladas,[4] keeping the point at $\cos\theta^* = 1$ fixed at the value determined by dispersion relations[5] and the optical theorem (where θ^* is the c.m. scattering angle for the pion). Hence, the normalization is known only to about ±12 to 15%. A future run is planned to measure the absolute normalization.

The errors quoted were obtained from a statistical analysis of the repeatability of repeated runs. The only region of the curve where the errors are significantly different from pure statistics (i.e., different by more than a factor of two) is that in which the recoil proton had nearly the same laboratory-system angle as the scattered pion. Corrections due to accidental and inelastic counts were 2% or less for all channels and all energies.

The results are listed in Table I, where θ^* is the center-of-mass angle of the scattered pion and $d\sigma/d\Omega$ is the differential cross section (in mb/sr). The corresponding graphs appear in Fig. 1.

In Fig. 2 we present a plot of the energy dependence of the coefficients of the various cosine power series adjusted to our data, and also to the data of Goodwin et al.,[6] Shonle,[7] Bergia et al.,[8]





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