Leptonic Decay Modes of the Hyperons*

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We have searched for the leptonic decay of the Λ^0 and Σ^-. The sensitivity of the experiment was such that 5–6 events should have been found according to the predictions of the "universal" V-A model of β decay. No examples of leptonic decay were observed.

THE β decay and μ decay of hyperons are expected in all models of the decay interactions. If direct Fermi-type couplings do not exist for these processes, the decay is nevertheless expected through the Fermi interaction of intermediate nucleons and θ mesons. For instance, a Feynman diagram for Λ^0 decay would be that shown in Fig. 1. The order of magnitude of the leptonic decay rates relative to the pionic rates, on the basis of a phase-space argument, might be expected to be of the order of $p^3V/60\pi^2$, where p is the momentum available in the leptonic decay, and V is the interaction volume. For an interaction radius of 10^{-13} cm, one might then expect that the two leptonic modes account for approximately 0.6% of Λ^0 decay and 2% of $\Sigma^\pm$ decay.

Recently Feynman and Gell-Mann[1] and Marshak and Sudarshan[2] have proposed that the V-A Fermi coupling which is successful in the understanding of β decay and μ decay might be extended also to hyperons, with the same coupling constant, in the spirit of universality of the Fermi interaction. This point of view is not only attractive theoretically, but also suggests an understanding of the large parity nonconservation effects in Λ^0 decay.[3] It yields well-defined decay rates and spectra:

$$N(p)dp=\frac{G^2}{\pi^3}M^2\left[(M+p)\left(\frac{2Q+2p-2E+M}{M}\right)^{\frac{1}{2}}-(M-p)\left(\frac{2Q-2p-2E+M}{M}\right)^{\frac{1}{2}}-4p\right]pdp, \quad (1)$$

$$p_t=\int N(p)dp.$$

Here M is the nucleon mass, Q the available kinetic energy in the decay, E and p are the energy and momentum of the charged lepton, and G is the universal coupling constant[2] defined by

$$H_{\text{int}}=8^{\frac{1}{2}}G\bar{\psi}\gamma_\mu\left(\frac{1-\gamma_5}{2}\right)\psi\bar{\psi}\gamma_\mu\left(\frac{1-\gamma_5}{2}\right)\psi.$$

From the β decay of O^{14}, G has been determined to be $G=(1.01\pm0.01)\times10^{-5}/M^2$.[1,4] In (1) we have neglected the small effect of the nuclear recoil on the spectrum and transition probability. The matrix element, after this neglect, is constant, so that (1) is just the phase-space spectrum.

In view of the definiteness of the theoretical prediction, the evidence in our so far fruitless search for these decay modes may not be without interest. We have looked among the several hundred examples of hyperon decay in our bubble chamber photographs. The chambers, 12-inch propane and hydrogen, in a 13-kilogauss field, had been exposed to pion beams in the 900–1300-Mev kinetic energy range at Brookhaven National Laboratory. The 3-body leptonic decays are distinguishable from the 2-body pionic decays by kinematical differences.

In the normal Λ^0 decay, $\Lambda^0\rightarrow\pi^-+p$, the two outgoing particles must be coplanar with the Λ^0, the transverse momenta must balance, and the Q must be 38 Mev. The probability that these conditions are met, within the measurement error, by the two charged prongs of a three-body leptonic decay, is quite small: we estimate that it is less than 10% for Λ's of known origin. In the case of the hydrogen chamber, a stopping of an incident pion and the presence of a V nearby in the picture are sufficient evidence that the two are associated. In the propane chamber we require, in addition to the pion stopping or star, a visible θ^0, before the other V can be considered a candidate for leptonic decay. This is

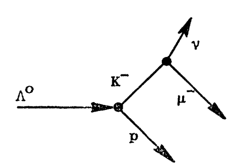

FIG. 1. Feynman diagram for Λ^0 decay.

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[2] R. Marshak and G. Sudarshan, Venice Conference on Elementary Particles, September, 1957 (unpublished).

[3] F. C. Crawford *et al.*, Phys. Rev. **108**, 1102 (1957); F. Eisler *et al.*, Phys. Rev. **108**, 1353 (1957).

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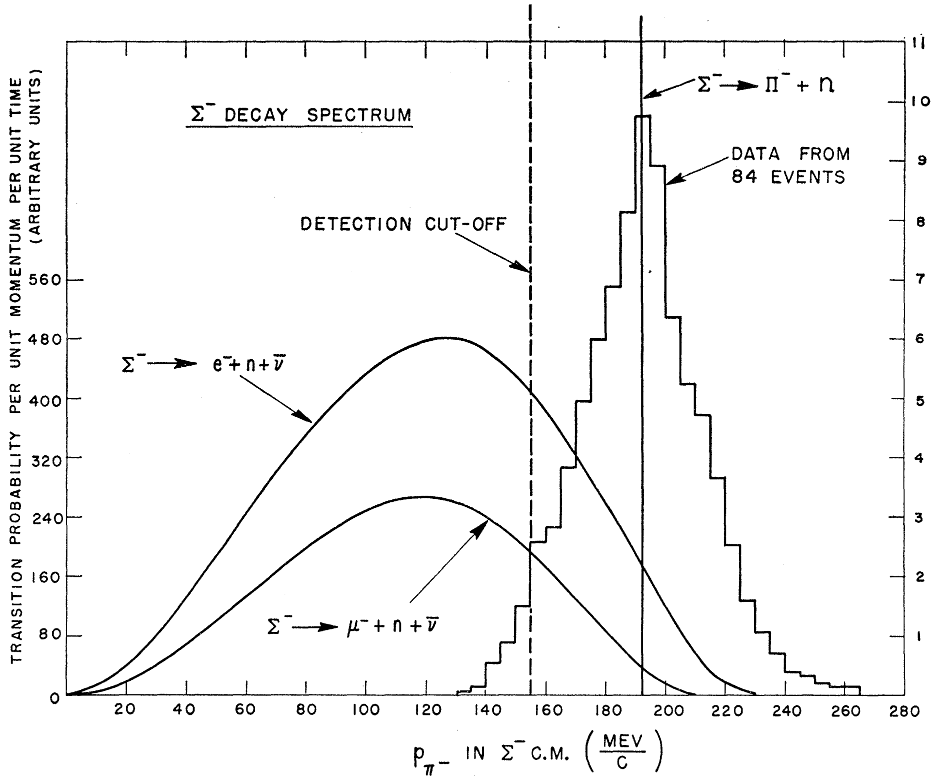

FIG. 2. Theoretical spectra for the leptonic decays of the Σ^- hyperon, and observed spectrum.

because the number of pion interactions is large and V's produced in the beam entrance window could be accidentally associated with a pion interaction in the chamber. We have found 100 Λ^0 decays in the hydrogen chamber and 170 Λ^0 decays in the propane chamber, all meeting the acceptance conditions. All of these were compatible with the charged pionic decay, within the accuracy of the measurement. No leptonic decays were observed. One example would correspond to $\frac{2}{3}/(0.9\times 270)=0.27\%$ for the leptonic decay rate relative to the charged. The factor $\frac{2}{3}$ here is the fraction of Λ^0 decays which are charged. $\frac{1}{3}$ of the Λ^0 decays are neutral[5] and not observed. This corresponds to leptonic decay rate of the order of 1.1×10^7 sec^{-1} or less, using $\tau_\Lambda = 2.4\times 10^{-10}$ sec^{-1}.[6]

The other case of hyperon decay which can be studied in these pictures is Σ^- decay. In Σ^- decay one charged secondary is observed, which offers then the sole means of identifying the decay mode. We have analyzed only events of the form $\pi^- + p \to \Sigma^- + \theta^+$. In these cases the Σ^- momentum is well known, so the transformation velocity to the Σ^- rest frame is accurately known. The transformation has been performed on the secondaries assuming that they have pionic mass. All observed cases were consistent with the momentum $p_\pi = 192$ Mev/c for the decay $\Sigma^- \to \pi^- + n$; in fact this analysis serves us now as a magnetic field calibration. Since the transformation on the secondary is performed for a particle of pionic mass, the lepton spectra of Fig. 2 are not strictly relevant. We have investigated in detail the distortion in these spectra produced by this procedure, and find that on the average the distortion is slight ($\sim 5\%$), and in a direction which makes the experiment slightly more sensitive. The analysis is tedious and the effect small; the calculations are therefore omitted here. From Fig. 2 we deduce that on the average 75% of the β and μ particles would be emitted with energies experimentally resolved from the monoenergetic pions. No leptonic decay was observed among the 84 well-measured Σ decays. One event in this sample would

TABLE I. Transition rate on the basis of the V-A universal theory and experimental sensitivity, for Λ^0 and Σ^- leptonic decays. The last row for each group is the *combined* transition rate for electronic and muonic decay.

	Transition rate in universal V-A theory (sec^{-1})	Experimental sensitivity, in sec^{-1}. Since no events are observed, the numbers quoted refer to one (unobserved) event.
$\Lambda^0 \to p + e^- + \bar{\nu}$	5.3×10^7	1.1×10^7
$\Lambda^0 \to p + \mu^- + \bar{\nu}$	1.3×10^7	1.1×10^7
$\Lambda^0 \to p + 2$ leptons	6.6×10^7	1.1×10^7
$\Sigma^- \to n + e^- + \bar{\nu}$	29×10^7	9.4×10^7
$\Sigma^- \to n + \mu^- + \bar{\nu}$	14×10^7	9.4×10^7
$\Sigma^- \to n + 2$ leptons	43×10^7	9.4×10^7

[5] Eisler, Plano, Samios, Schwartz, and Steinberger, Nuovo cimento **5**, 1700 (1957).

[6] According to a compilation of our own results and those of other laboratories (to be published).

have corresponded to a leptonic decay probability of $1/(0.75\times84)=1.6\%$. Using the Σ^- lifetime, $\tau_\Sigma=1.7\times10^{-10}$ sec, this corresponds to a combined leptonic decay rate of the order of $9.4\times10^{+7}$ sec^{-1} or less.

These results are tabulated in Table I. Both in the case of Λ^0 and Σ^0 decay the experiment should have been sufficiently sensitive to see leptonic decays with the probability predicted in the universal V-A theory. In each case 5–6 events should have been observed, but none were. This, it seems to us, makes the model untenable in this form for these hyperons. It need hardly be added that this is no way detracts from its success in β and μ decay. However, the simple extension of coupling (3) to the Λ^0 and Σ^- is very unlikely in view of these results.

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Photoproduction of K^+ Mesons in Hydrogen*

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K^+ mesons produced in a liquid hydrogen target bombarded by the 1100-Mev bremsstrahlung of the California Institute of Technology synchrotron have been observed. It has been found that the K^+ mesons are produced in association with Λ^0 hyperons, in accordance with the law of associated production of strange particles. The K^+ mesons were momentum-analyzed in a magnetic spectrometer and identified by their energy loss in three scintillation counters, the very large background due to pions and protons being virtually eliminated by means of time-of-flight discrimination. The differential cross section for the reaction $\gamma+p\rightarrow K^++\Lambda^0$ has been measured at photon energies of 960 Mev, 1000 Mev, and 1060 Mev at various K^+-meson laboratory angles between 15 degrees and 45 degrees. This cross section shows little variation with photon energy between 960 Mev and 1060 Mev or with center-of-momentum angle over the range investigated.

1. INTRODUCTION

When the electron synchrotron at the California Institute of Technology began operation at an energy of 1100 Mev, a search was begun for K^+ mesons produced in photon-nucleon collisions. Because of the lack of a source of photons of sufficiently high energy, the photoproduction of the strange particles had not been previously observed. It was, therefore, desired to ascertain whether K^+ mesons are produced at all in photonuclear reactions and, if so, whether they are produced according to the law of associated production of strange particles.[1]

Three reactions involving K^+ mesons are energetically possible with photons of energies less than 1100 Mev:

$$\gamma+p\rightarrow K^++\Lambda^0 \text{ (threshold 910 Mev)}; \quad (1)$$

$$\gamma+p\rightarrow K^++\Sigma^0 \text{ (threshold 1040 Mev)}; \quad (2)$$

$$\gamma+p\rightarrow K^++n \text{ (threshold 630 Mev)}. \quad (3)$$

The first two reactions conserve strangeness and were expected to occur, whereas the third should be very much weaker according to the theories of strange particles.[1]

The three reactions above can be distinguished by differences in their kinematic relations arising from the differences in the masses of Λ^0, Σ^0, and n. Thus K^+ mesons produced at a given angle and a given energy must be produced by photons of different energy for the three reactions. This is illustrated quantitatively in Fig. 1. No information has been obtained in the present experiment about the production of K^+ with Σ^0 since photons of energies greater than the bremsstrahlung upper limit would have been required to produce K^+ mesons from reaction (2) at the angles and energies observed. Furthermore, by lowering the synchrotron energy below that required for reaction (1), it was found as expected that less than 5% of the K^+ mesons can come from reaction (3). Thus, the K^+ particles observed in the present experiment are produced with Λ^0 in reaction (1), and the data are reduced to differential cross sections for this reaction.

Preliminary results of the present experiment have been reported previously.[2] The cross sections presented here differ somewhat from the earlier ones not only because additional data have been obtained, but also because of changes in the assumed bremsstrahlung spectrum based on pair spectrometer measurements,[3] and because of a small change in the beam monitor calibration.[4]

K^+-particle photoproduction is also being investigated at Cornell. Silverman, Wilson, and Woodward[5]

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