SEARCH FOR LEPTONIC DECAYS OF THE SIGMA*

Jack Leitner,† Paul Nordin, Jr., Arthur H. Rosenfeld, Frank T. Solmitz, and Robert D. Tripp
Lawrence Radiation Laboratory, University of California, Berkeley, California
(Received July 17, 1959)

As part of a continuing study of 8000 K absorptions in hydrogen[1] we have examined ~2000 Σ decays for evidence of leptonic modes.

In order to obtain events which were both unambiguous and accurately measurable, it was required that the length of the Σ track be greater than 0.5 mm, and the length of the decay-product track be greater than 5 cm and have a dip less than 60°. Of the total sample, 750 Σ^- and 250 $\Sigma^+ \rightarrow \pi^+ + n$ (effectively 500 Σ^+) satisfied the above criteria.

The search for leptonic decay modes was carried out by studying the (lab) momentum distribution of the Σ-decay products (shown in Fig. 1).[2] The vast majority of the events lies within the region ~160 to 224 Mev/c—the kinematic limits of the normal Σ-decay modes, $\pi^\pm + n$. It is therefore clear that careful consideration must be given to the problem of momentum measurement before attempting to estimate the very small leptonic-mode contribution.

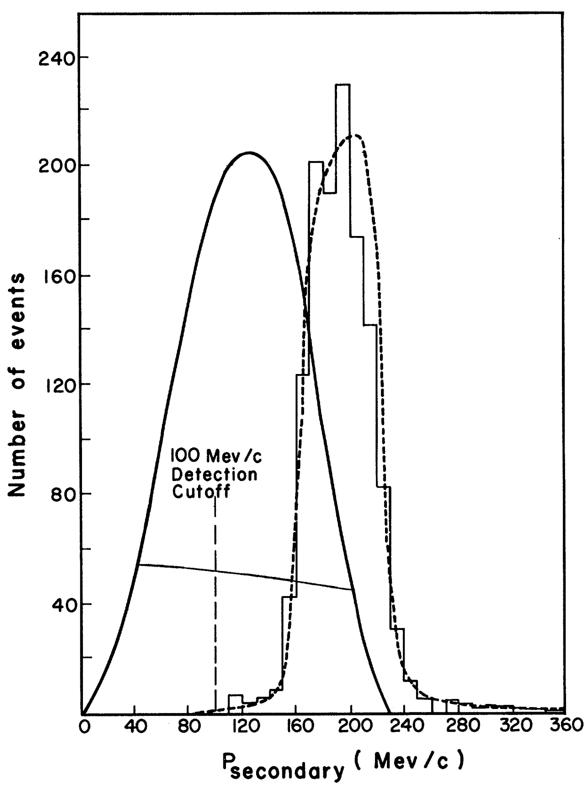

FIG. 1. Histogram of the $\Sigma^\pm$ decay secondaries. The solid curve is the phase-space spectrum of $\Sigma^- \rightarrow e^- + n + \nu$. The broken curve is the theoretical spectrum of $\Sigma^\pm \rightarrow \pi^\pm + n$, taking account of experimental resolution.

In order to investigate the effects of multiple and (unobservably) small-angle single scattering, we studied the momentum spectrum from the reaction $K^- + p \rightarrow \Sigma^- + \pi^+$ at rest, which yields a unique pion momentum of 174 Mev/c. One should expect the measured distribution to be symmetrically distributed about 174 Mev/c (when plotted against curvature), the spread arising mostly from Coulomb scattering of the pion. Multiple scattering should produce a Gaussian distribution of half-width σ, which, for tracks of 15 cm mean length, 30° average dip, and $\beta = 0.8$, is $\sigma = \pm 11$ Mev/c. The systematics of single scattering leads one to expect that about 8 % of the total number of events should have momenta p_π outside the interval $174 \pm 2\sigma$ Mev/c with a distribution $(174 - p_\pi)^{-3} p_\pi$.[3] The calculated momentum spread due to the combined effects of multiple and single scattering is shown in the dashed curve of Fig. 2 (plotted against momentum and thus asymmetric). The measured momentum distribution $g(p_\pi)$ of these selected primary pions is shown as the histogram of Fig. 2. On the basis of the excellent agreement between the observed and theoretical momentum spread, we conclude that our momentum errors are adequately understood.

It is convenient to use $g(p_\pi)$ as the composite error function for momentum measurement. With appropriate adjustment to account for the difference in mean momentum, folding $g(p_\pi)$ into the known c.m.-lab transformation[4] for the reaction $\Sigma^\pm \rightarrow \pi^\pm + n$, we obtain the dashed curve of Fig. 1. The agreement between the observed spectrum and that expected from the normal pion decay is excellent, indicating that the contribution of other decay modes is indeed small.[5]

In the UFI (universal Fermi interaction) theory of Feynman and Gell-Mann,[6] leptonic-mode rates are ~2 to 6%;[7] leptons should be emitted with a phase-space momentum spectrum (shown as the solid curve of Fig. 1). Since the leptonic spectrum extends well into the pionic spectrum, a detection cutoff must be chosen in order to obtain upper limits on the rate of leptonic decay. The choice of cutoff is somewhat arbitrary; we choose it at $p_\pi = 100$ Mev/c for several reasons.

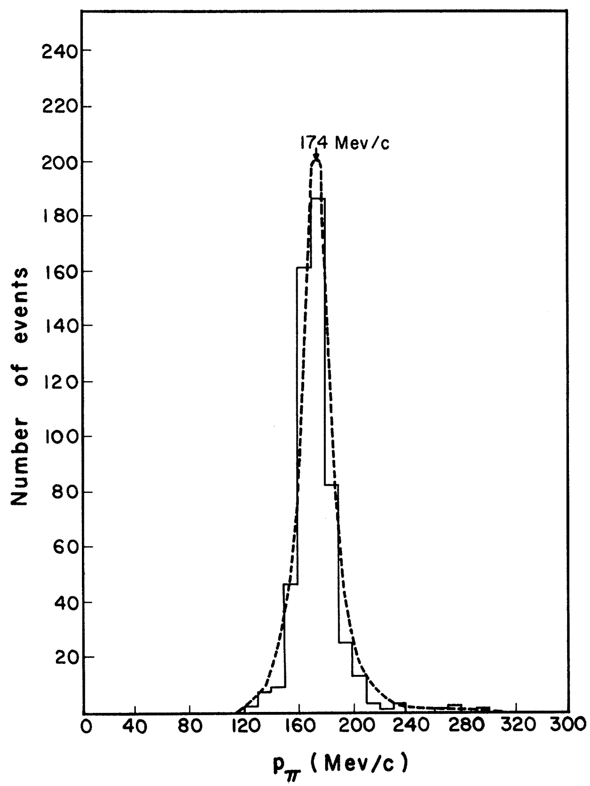

FIG. 2. Histogram of the $\pi^\pm$ momentum distribution from $K^- + p \to \Sigma^- + \pi^+$. The dashed curve represents the calculated spread due to Coulomb scattering.

First, the background of single-scattered pions and pions from radiative decay[5] should be negligible below 100 Mev/c. Second, electrons with momenta below the cutoff should be distinguishable (with high efficiency) from pions of the same momentum, which have an ionization density of 3.5 times minimum.

We have seen no Σ-decay secondaries with momenta below 115 Mev/c. Since the fraction of phase space below the 100-Mev/c cutoff is 33 %, we obtain an upper limit for the Σ^--electronic decay rate, for example, of $f(\Sigma^- \to e^- + n + \nu) \leq (750 \times 0.33)^{-1} = 0.4\,\%$. Branching fractions for the remaining modes[8] are given in the first column of Table I.

If the results of the present experiment are combined with the world total of published data, the rates shown in the second column of Table I are obtained.[9] In spite of the ambiguity inherent in the choice of detection cutoff it is clear from Table I that the observed rates are less than those expected on the basis of the UFI theory by about an order of magnitude. It has recently been shown that a similar discrepancy exists in Λ^0

Table I. Upper limits to the branching fractions for leptonic decays.

	Maximum Rates (%)	
Leptonic mode	This experiment	Total world data
$\Sigma^- \to e^- + n + \nu$	0.4	0.2
$\Sigma^+ \to e^+ + n + \nu$	0.6	0.4
$\Sigma^- \to \mu^- + n + \nu$	0.4	0.2
$\Sigma^+ \to \mu^+ + n + \nu$	0.5	0.3
$\Sigma^- \to \Lambda^0 + \begin{Bmatrix} e^- \\ \mu^- \end{Bmatrix} + \nu$	0.1	...
$\Sigma^+ \to \Lambda^0 + \begin{Bmatrix} e^+ \\ \mu^+ \end{Bmatrix} + \nu$	0.2	...

leptonic decay.[10] While these results in no way detract from the enormous success of the Universal Fermi theory in nonstrange and K-particle weak interactions, it is clear that a simple extension of the Fermi interaction with the inclusion of $\Sigma\bar{n}$ and $\bar{\Lambda}n$ terms cannot be considered an adequate model for the description of hyperon decays.

*This work supported in part by the U.S. Atomic Energy Commission and the Office of Scientific Research.

†On leave from Syracuse University, Syracuse, New York.

[1]Alvarez, Bradner, Gow, Rosenfeld, Solmitz, and Tripp, Nuovo cimento 5, 1026 (1956).

[2]The data shown in Fig. 1 have been corrected for a small in-flight contamination of ~ 3%

[3]Alvarez, Leitner, Rosenfeld, and Solmitz, Berkeley Engineering Report 4310-03 (unpublished).

[4]Leitner, Nordin, Rosenfeld, Solmitz, and Tripp, University of California Radiation Laboratory Report UCRL-8737, May 1959 (unpublished).

[5]S. Barshay and R. E. Behrends, Brookhaven Report BNL-3956, Dec. 1958 (unpublished).

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

[7]In the original presentation of reference 6, the Σ^+ leptonic decay is absolutely forbidden. However, if the $\Delta S = 1$ selection rule is relinquished, the Σ^+ leptonic decay is allowed and should occur with a relative frequency of ~ 3%.

[8]Note that, to within a factor of ~ 2, these upper limits depend upon the choice of detection cutoff. For example, if the cutoff is taken at 135 Mev/c, about 2 standard deviations from the minimum momentum available to the pion from $\Sigma^\pm \to \pi^\pm + n$ decay, the upper limit on $\Sigma^- \to e^- + n + \nu$ decay becomes $(1 \pm 4)/750 \times 0.66 = 0.2\,\% \pm 1.0\,\%$.

[9]The efficiency for the detection of the modes $\Sigma^{\pm} \rightarrow \Lambda^0 + e^{\pm} + \nu$ is 100% because of the low maximum electron momentum, leading to the lower rates shown in Table I. However, mere phase-space considerations indicate an expected rate of $\sim 10^{-4}$.

[10]Crawford, Cresti, Good, Kalbfleisch, Stevenson, and Ticho, Phys. Rev. Letters 1, 377 (1958); Orear, Nordin, Rosenfeld, Solmitz, and Tripp, Phys. Rev. Letters 1, 380 (1958); F. Eisler et al., Nevis Report No. 67, March 1958 (unpublished).

CAUSE OF THE MINIMUM IN THE EARTH'S RADIATION BELT*

S. F. Singer
Department of Physics, University of Maryland, College Park, Maryland
(Received June 29, 1959)

In earlier publications[1] we have put forth the hypothesis that the trapped radiation encountered by satellites[2] at low altitudes near the equator consists of fast protons; they arise from the decay of upward-moving cosmic-ray albedo neutrons which originate in the earth's atmosphere. We also calculated the expected altitude dependence and energy spectrum of these protons.

It is our view that solar corpuscular radiation, connected with magnetic storms and aurora, must exist in the trapped condition at higher latitudes and altitudes[3] and is therefore distinct in origin as well as in location from the radiation belt found at the equator at low altitudes.

One of the attractive features of the cosmic-ray neutron radiation belt is the fact that its injection rate can be accurately calculated from cosmic-ray data. Therefore there exists the possibility of using the measured intensity to determine the density of the outer atmosphere of the earth. If only the density of the neutral component of the exosphere were to control the particle lifetime and therefore the equilibrium intensity, then the radiation belt intensity should increase monotonically with altitude. If, however, there are additional factors limiting the lifetime, then the intensity would fall off beyond a certain altitude and therefore show a maximum, which we tentatively placed at 1 to 2 earth radii.[1]

Experimental results from the space probes[4,5] seem to have borne out this hypothesis. Two distinct maxima are found: the one at $1.5R_E$ (earth radii) can presumably be identified with the cosmic-ray radiation belt and the one at 3-4 earth radii with the solar radiation belt.

However, it has been argued that both belts may be of solar origin[2] with the minimum ("slot") at $\sim 2R_E$ due to some other cause, for example an instability of the earth's magnetic field at this location,[6] or as another possibility the effect of the large magnetic anomaly at Capetown.[7] If either of these views is correct, then we will have little chance of deriving atmospheric densities from measured radiation belt intensities.

In order to decide among the various possibilities, it seemed worth while to calculate the expected altitude dependence of the cosmic-ray belt by incorporating in more detail the breakdown of the adiabatic condition.[1]

We use the Alfven discriminant[8] $x \equiv \rho\ \mathrm{grad}B/B$, where ρ is the particle's radius of curvature. We can write x also as $(m\beta c/B)(3M/r^4)(Mr^{-3})^{-1} \propto \beta r^2$. Here $\beta = V/c$ and M is the earth's magnetic dipole moment.

In our calculation we will assume that the lifetime (and therefore intensity) is primarily determined by the atmospheric density for particles of small x. In other words, at very low altitudes the intensity will be primarily controlled by atmospheric density but at higher altitudes, or for large momenta, the lifetime is limited, as the particle's pitch angle changes slightly on each of its many reflections from the mirror points. Just at what point this breakdown of the adiabatic condition occurs cannot be easily decided from a priori considerations. However, the work of Northrop et al. indicates[9] that the breakdown is quite sharp and we therefore take the lifetime to be limited by a factor $\exp[-(x^2/b^2)]$. This function drops rapidly when $x \geqslant b$. We can therefore derive a maximum value of β at each altitude:

$$\beta_{\max} = b/r^2. \tag{1}$$

$\beta_{\min}$ is of course given by the conditions of the experiment and depends on such details as the thickness of the counter wall, etc.

To incorporate this refinement into the earlier theoretical discussion[10] we define the differential directional concentration:

$$n(\beta, \alpha_e, r_e) = \bar{\eta}(C_2/2\pi)(C_3\gamma)^{-1}\beta^{-\gamma+2}, \tag{2}$$