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We have examined the up-down asymmetry of electrons from the decay $\Sigma^- \to n + e^- + \bar{\nu}$ using polarized Σ^-'s produced via the reaction $K^- + p \to \Sigma^- + \pi^+$ at 400 MeV/c. This leads to a g_A/g_V which somewhat favors Willis' solution B,[1] unlike the recent[2] $\Sigma^- \to \Lambda + e^- + \bar{\nu}$ rate which favors Willis' solution A.

I. SELECTION OF EVENTS

Although some leptonic decays were found in the scan, most of them were obtained from the measurement of all Σ^- events within the fiducial volume, about 50 000 of which passed the usual production and decay hypothesis. Most of these were measured on the Spiral Reader measuring machine. Those events that did not pass the usual hypothesis with confidence level greater than 10^{-5} were fit to the hypotheses:

$$K^- + p \to \Sigma^- + \pi^+ \longrightarrow \left\{ \begin{matrix} e^- \\ \mu^- \\ \pi^- \end{matrix} + \text{missing mass} \right\}.$$

Events for which the missing mass for the electron hypothesis was greater than the neutron mass were investigated further. In addition, we subjected to missing-mass fits any events for which the confidence

level for the usual decay hypothesis was between 10^{-5} and 5×10^{-2}, the measured momentum of the decay product was less than 170 MeV/c in the rest frame of the Σ^- (193 MeV/c for ordinary decay), and the measured momentum was pulled more than two standard deviations in order to fit the usual decay. One further source of events was those for which no fits were obtained, but for which the decay secondary had a laboratory momentum less than 130 MeV/c. Most of these events were the result of a poor measurement or a kink in the decay π^- which the measurer had not noticed. The remainder were considered leptonic- and radiative-decay candidates and were remeasured at least once on a Franckenstein measuring machine. After elimination of more candidates by these remeasurements and a careful examination for kinks in the tracks, 107 events remained.

The ionization of the decay tracks was examined on this sample; 69 events were considered π^- or μ^- or unidentifiable by ionization, 2 were μ^- where the μ^- decayed to an e^-, and 36 were identified as electrons. Presumably there were a few e^- events among the 69 radiative-decay candidates where the particle is not identifiable by ionization. The momentum spectrum of electrons is seen in Fig. 1.

Of the electron events 32 had electron laboratory momentum less than 145 MeV/c and thus were visually identifiable as electrons by ionization. The other four had laboratory momenta from 156 to 175 MeV/c. For these, as well as for 10 others that subsequently were considered unidentifiable or nonminimum tracks, the gaps between bubbles were measured, and a gap length distribution was made. The distribution should follow an exponential behavior, after a correction

is made for small gaps because of finite bubble size. The mean gap length then is proportional to β^2, so if one measures another track on the frame (preferably associated with the event), one obtains

$$\frac{\text{mean gap length of candidate}}{\text{mean gap length of other track}} = \frac{\beta^2 \text{ of candidate}}{\beta^2 \text{ of other track}} .$$

In this way, obvious low-momentum electrons gave, on the average, $\beta^2 \approx 1.0 \pm 0.2$, and the four candidates had $\beta^2 \approx 1.0$ with a statistical error such that a pion's β^2 was at least 1.5 standard deviations away. The four events also all looked minimum-ionizing from examination by eye.

For the 36 electron events the momentum of the Σ^- at decay is greater than 80 MeV/c, the length of the Σ^- is greater than 1mm, and the dip angle of the electron is less than 70 deg. No electron candidates were eliminated because of these criteria.

II. THEORY AND RESULTS

One can write the Hamiltonian for leptonic baryon decay as $H = (G/\sqrt{2})\, J_\lambda \ell^\lambda$, where ℓ^λ is the usual lepton current, $\bar{u}_e \gamma^\lambda (1 + \gamma_5) u_\nu$, and J_λ is the baryon current, $V_\lambda + A_\lambda$, with $V_\lambda = g_V \gamma_\lambda$ and $A_\lambda = g_A \gamma_\lambda \gamma_5$. The baryon matrix element for $\Sigma^- \to n + e^- + \bar{\nu}$ is then $\langle n | \gamma_\lambda (g_V + g_A \gamma_5) | \Sigma^- \rangle$. If we assume time reversal invariance, g_A and g_V are both real. For polarized baryons, this gives[3] a momentum spectrum for the electron

$$I(\hat{q}) = 1 + \alpha \langle \underset{\sim}{\sigma}_\Sigma \rangle \cdot \hat{q} ,$$

where

$$\alpha = 2 \frac{g_A}{g_V} \left[\frac{1 - g_A/g_V}{1 + 3 (g_A/g_V)^2} \right] .$$

Here, $\hat{q}$ is the electron-momentum unit vector.[4]

The likelihood function for the momentum distribution of the electron is

$$\mathcal{L}(\alpha) = \prod_{i=1}^{36} (1 + \alpha \langle \underset{\sim}{\sigma}_{\Sigma} \rangle_i \cdot \hat{q}_i).$$

The Σ^- polarization, $\langle \underset{\sim}{\sigma}_{\Sigma} \rangle$, is computed for each event, using the partial-wave analysis of the $\Sigma\pi$ system.[5] Our average polarization is 0.5 in magnitude.

The logarithm of $\mathcal{L}$ is plotted in Fig. 2, yielding $\alpha = 0.29 \pm 0.45$. Positive α means that electrons are emitted preferentially in the same direction as the Σ^- polarization, which is opposite to ordinary beta decay. Figure 3 is a plot of α vs g_A/g_V. Our value of α is near the maximal value, $\alpha = 1/3$, and thus by itself does not give a very good determination of a central value for g_A/g_V.

Cabibbo's theory assumes that A_λ and V_λ are members of SU_3 octets of axial and vector currents.[6] Further, $\Delta S = 0$ and $\Delta S = 1$ leptonic-decay baryon currents are members of the same octets but have different strengths:

$$J^i_\lambda = \cos\theta_i \, J^i_\lambda (\Delta S = 0) + \sin\theta_i \, J^i_\lambda (\Delta S = 1)$$

with $i = A, V$. A_λ and V_λ each contribute D and F type SU_3 couplings, because $8 \otimes 8$ contains a symmetric and an antisymmetric octet. After computation of the SU_3 coefficients, one obtains:

Decay	g_A	g_V
$n \to p + e^- + \bar{\nu}$	$(D_A + F_A)\cos\theta_A$	$(D_V + F_V)\cos\theta_V$
$\Sigma^- \to n + e^- + \bar{\nu}$	$(D_A - F_A)\sin\theta_A$	$(D_V - F_V)\sin\theta_V$

Here we include the neutron beta decay in order to compare the signs.

From conserved-vector-current (CVC) theory, we have $F_V = 1$ and $D_V = 0$. Setting $\theta_A = \theta_V$, which nearly appears to hold experimentally,[7] one has $(g_A/g_V)_{n \to p} = D_A + F_A$ and $(g_A/g_V)_{\Sigma^- \to n} = F_A - D_A$.

Willis et al.[1] obtain two best-fit solutions to all leptonic baryon decays. These are shown in Table I along with the predicted value of g_A/g_V. More recently Brene et al.[7] and Carlson[8] have further investigated solution A. Their results as well as the two solutions of Willis are shown in Fig. 3, where a comparison is made with this experiment. Our likelihood function favors solution B over solution A by a probability ratio of 10.5, or solution B over Carlson's solution by a probability ratio of 16.0. On the other hand, recent evidence of Barash et al.[2] on the decay rate $\Sigma^- \to \Lambda + e^- + \bar{\nu}$ strongly favors solution A, so that our limited sample of polarized Σ^- leptonic decays leads to a mild (less than two standard deviations) inconsistency with other baryon leptonic-decay results when they are related to each other through Cabibbo's theory.

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FOOTNOTES AND REFERENCES

*This work was done under the auspices of the U. S. Atomic Energy Commission.

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2. N. Barash, T. B. Day, R. G. Glasser, B. Kehoe, R. Knop, B. Sechi-Zorn, and G. A. Snow, Phys. Rev. Letters 19, 181 (1967).

3. G. Källén, Elementary Particle Physics, (Addison-Wesley, Reading, Mass., 1964), p. 361. Källén uses the conventional beta-decay notation, with $\gamma_\lambda(g_V - g_A\gamma_5)$, so that our α differs from his by the appropriate minus sign. Willis et al. use the notation $G_A/G_V = 1.15$ for neutron decay in Table II, but tabulate something called A/V for $\Sigma^- \rightarrow n + e^- + \bar{\nu}$ in Table III. This quantity A/V is actually $-G_A/G_V$ in their notation and $-g_A/g_V$ in ours. The notation A/V was apparently chosen following Cabibbo (see Table I of Ref. 6), the sign convention being established by $A/V = -1.18$ for $n \rightarrow p + e^- + \bar{\nu}$. We are grateful to Prof. J. D. Jackson for pointing this out.

4. We neglect the $\Sigma^- - n$ mass difference. If we do not neglect it, then α is a more complicated function, with terms for the neutron energy and the electron momentum. These corrections turn out to be small and are thus neglected. There is very little change in our best answer for g_A/g_V if we use the more complicated expression for α.

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6. N. Cabibbo, Phys. Rev. Letters 10, 531 (1963).
7. N. Brene, L. Veje, M. Roos, and C. Cronström, Phys. Rev. 149, 1288 (1966).
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Table I. Best-fit solutions of Willis to all leptonic baryon decays, and predicted values of g_A/g_V.

Solution	D_A	F_A	$(g_A/g_V)_{n\to p}$	$(g_A/g_V)_{\Sigma^-\to n}$
A	0.742	0.436	1.178	-0.306
B	0.377	0.749	1.226	0.372

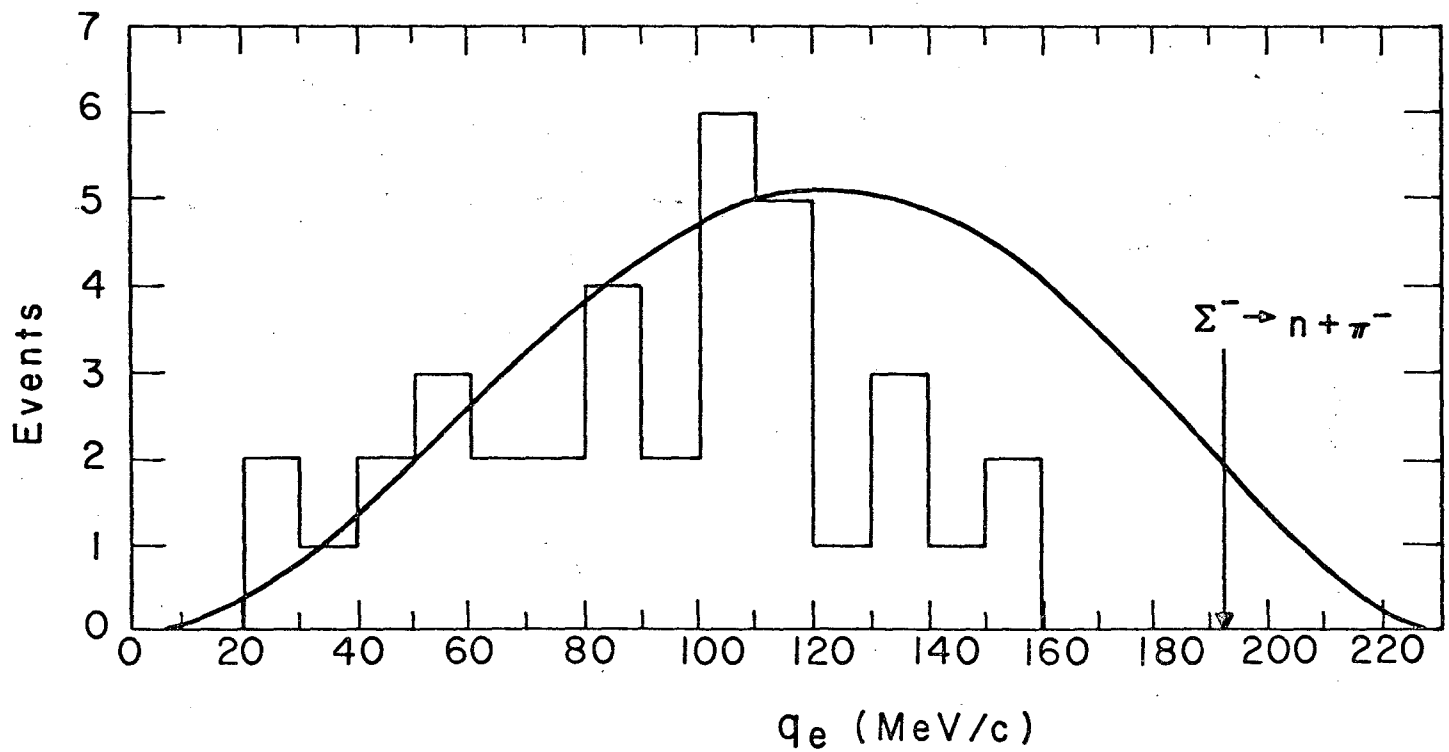

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Fig. 1. Momentum of electrons in the rest frame of the Σ^-. The smooth curve is the phase-space distribution on the basis of 50 000 Σ^- decays and a branching ratio of 1:800.

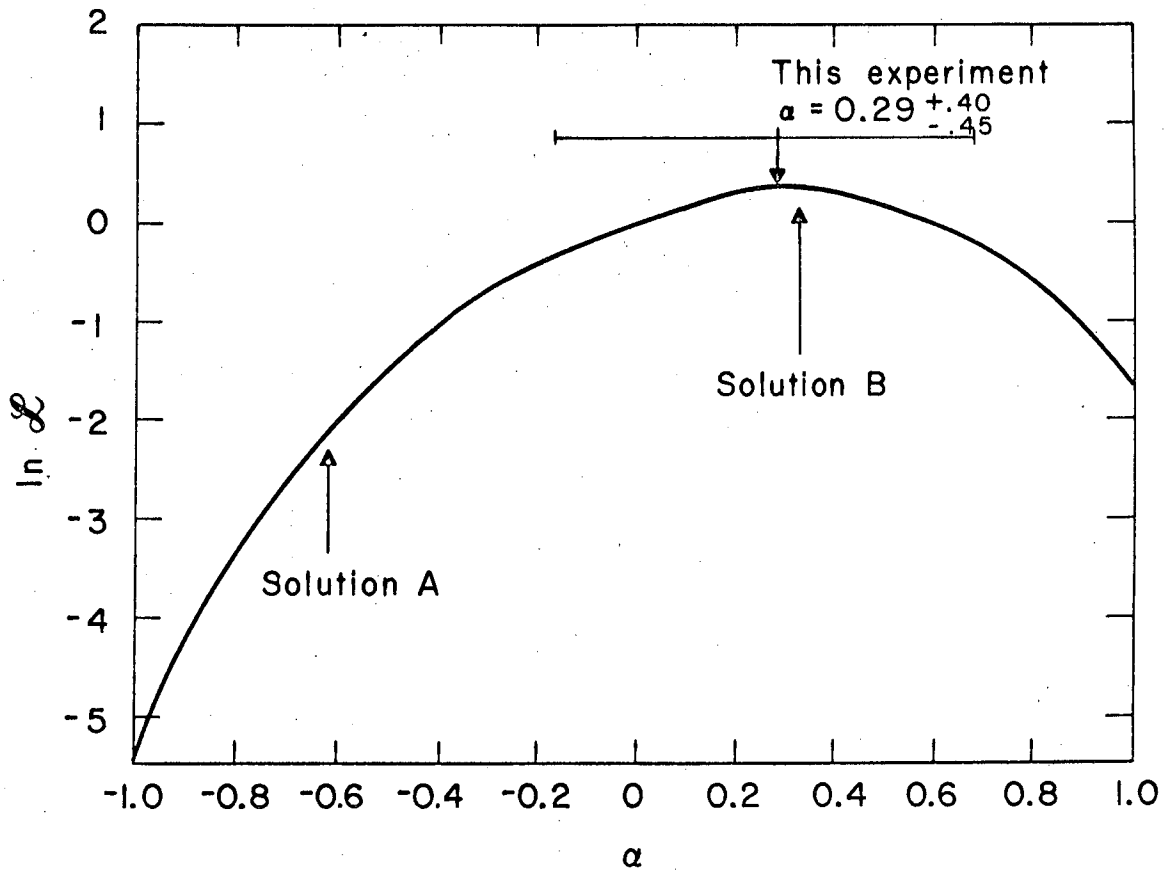

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Fig. 2. Plot of ln $\mathcal{L}$ vs α.

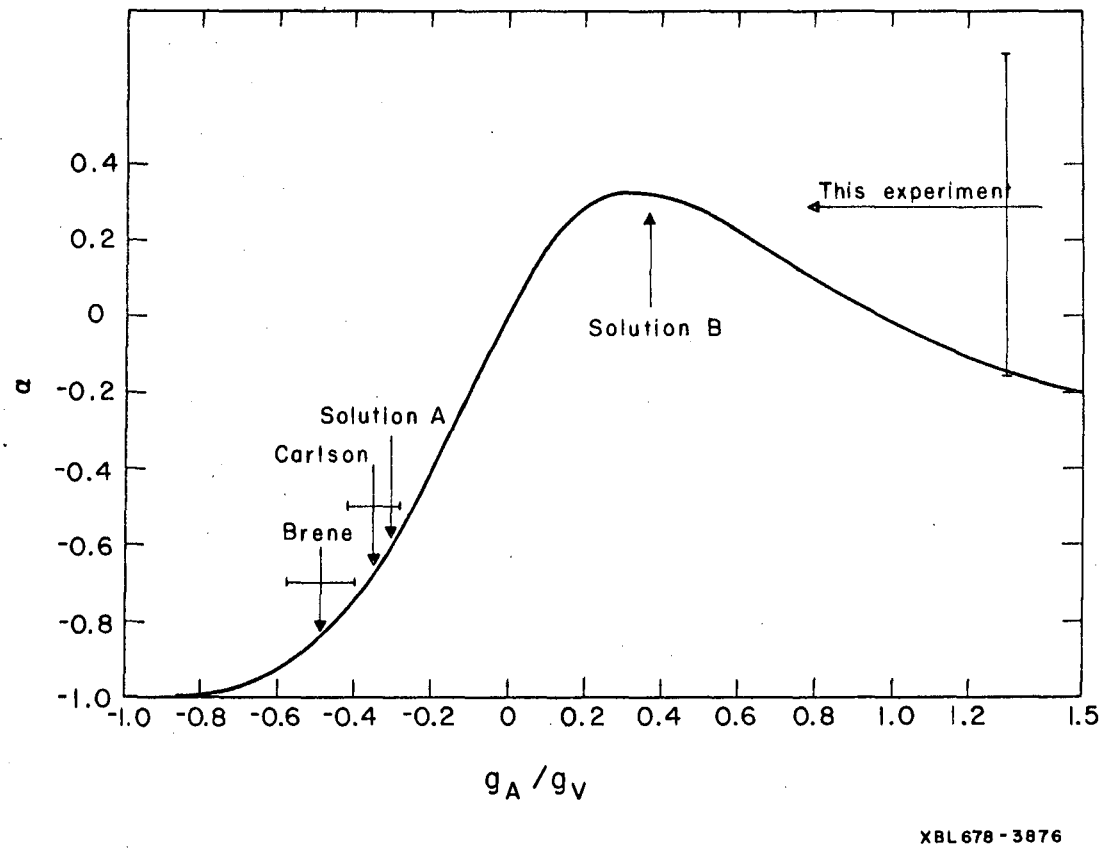

Fig. 3. Plot of α vs g_A/g_V. The predicted values of Willis, Brene, and Carlson are indicated.

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