MEASUREMENT OF THE ASYMMETRY PARAMETER FOR Σ^- LEPTONIC DECAY*

Lawrence K. Gershwin, Margaret Alston-Garnjost, Roger O. Bangerter,
Angela Barbaro-Galtieri, Frank T. Solmitz, and Robert D. Tripp
Lawrence Radiation Laboratory, University of California, Berkeley, California
(Received 22 April 1968)

Using polarized Σ^- hyperons, we have measured the up-down asymmetry of leptons in the decay $\Sigma^- \rightarrow nl^-\bar{\nu}$. This leads to a value of $g_A/g_V = 0.05^{+0.23}_{-0.32}$, in reasonable agreement with the Cabibbo theory for leptonic decays.

Leptonic decays of various baryons are related through Cabibbo's theory[1] used in conjunction with the hypothesis of conserved vector current. Three measurements suffice to establish the free parameters, namely, the Cabibbo angle θ and the D and F couplings. The six different measurements so far performed on baryon leptonic decays are all consistently related through the theory.[2] Here we report a seventh, and heretofore unmeasured, quantity which is also in agreement.

The experiment consisted in taking 1.3×10^6 pictures in the Berkeley 25-in. hydrogen bubble chamber exposed to a K^- beam ranging from 300 to 450 MeV/c, the vast majority of which occur near the $Y_0^*(1520)$ resonance (390 MeV/c). 49 electron and eight muon events of the type $K^-p \rightarrow \Sigma^-\pi^+$, $\Sigma^- \rightarrow nl^-\bar{\nu}$ were obtained. From these events the decay asymmetry of leptons from Σ^- hyperons, whose polarizations are known from a multichannel partial-wave analysis,[3] was then measured. This asymmetry is related to the ratio of the axial vector to vector coupling constants, which in turn is related to the D and F couplings.

(I) Selection of events.—We found that scanning criteria on curvature and ionization cannot be used very well to identify Σ^- leptonic decays. Therefore the full sample of 70 000 Σ^- decays was measured. About 1500 events which did not pass the usual two-body or three-body production and nonleptonic-decay hypotheses with an overall confidence level of greater than 10^{-4} fitted the hypotheses

$$K^-p \rightarrow \Sigma^-\pi^+ \quad \llcorner\!\rightarrow (e^-,\ \mu^-,\ \text{or}\ \pi^+) + \text{missing mass}. \qquad (1)$$

About 500 events, for which the missing mass for the leptonic-decay hypotheses was greater than the neutron mass, were investigated further. Visual inspection of the events showed that the majority of them were either the result of a poor measurement or of a small-angle scattering or decay of the pion. The remainder were considered candidates and were remeasured at least once.[4] After these remeasurements had eliminated more candidates and after further examination for scatterings and decays in the tracks, 182 events remained.

The major source of nonleptonic background among these candidates comes from radiative pionic decay; above 125-MeV/c momentum in the Σ rest frame the radiative-decay probability exceeds the probability for electron decay. However, for momenta in this region or below, pions are usually distinguishable from electrons by ionization. For positively identifying an electron we first adopted the criteria that the momentum of the electron in the Σ^- c.m. be less than 150 MeV/c and that the dip angle of the electron be less than 70 deg. Electrons with a lab momentum below 145 MeV/c were separated from pions and muons by visual inspection of the ionization. For those events above this momentum bubble-gap counting was employed to compare the β^2 of the electron candidate with another track on the frame (preferably associated with

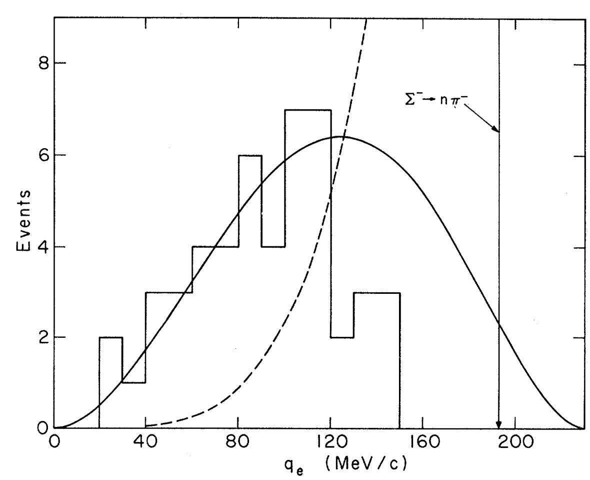

FIG. 1. Momentum of electrons in the rest frame of the Σ^-. The solid curve is the phase-space distribution of $\Sigma^- \rightarrow ne^-\bar{\nu}$ for a branching fraction of 1:800; the dashed curve, of $\Sigma^- \rightarrow n\pi^-\gamma$. Both curves are normalized to 63 000 Σ^- decays that satisfy the imposed cuts.

the event). This yielded four additional unambiguous electron events with lab momenta up to 172 MeV/c. The momentum distribution for all accepted electron events is shown in Fig. 1. The lower part of the spectrum is in good agreement with the phase-space prediction.

One cannot so easily distinguish muons from radiative pionic decay by means of ionization. Five muons came to rest in the chamber and so gave unambiguous signatures. For the remainder we considered as candidates only those events with a momentum in the Σ c.m. of less than 70 MeV/c, so that the a priori probability that it is a muon exceeds that of radiative pion decay by at least a factor of 5. This yielded three additional events for which ionization favored the muon hypothesis, and one additional event in which a pion came to rest. All muons had momenta below that which could arise from collinear π decay in flight.

(II) Results.—The angular distribution of leptons from polarized baryons is

$$I(\hat{q}) = 1 + \alpha\langle\vec{\sigma}_\Sigma\rangle\cdot\hat{q}, \qquad (2)$$

where the decay-asymmetry parameter α is given approximately by[5,6]

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

Here $\hat{q}$ is the lepton momentum unit vector, β is the lepton velocity, and $\langle\vec{\sigma}_\Sigma\rangle$ is the Σ^- polarization, which is computed for each event by using the multichannel partial-wave analysis.[3] The average magnitude of the Σ^- polarization is 0.5. A likelihood function ,

$$\mathfrak{L}(\alpha) = \prod_i (1 + \alpha\langle\vec{\sigma}_\Sigma\rangle_i\cdot\hat{q}_i)$$

is then computed as a function of α. This yields a value $\alpha = -0.13 \pm 0.41$ for the electrons.[7] Since universality requires that g_A/g_V be the same for electrons and muons, and since the data are limited, we combine the two samples (although the muons contribute very little both because of their number and because of the β dependence). Using the expressions of Harrington[6] rather than Eq. (3) to relate the decay asymmetry to g_A/g_V, we obtain from a likelihood computation two values, $g_A/g_V = 0.05^{+0.23}_{-0.32}$ and $g_A/g_V = 1.3^{+0.9}_{-10}$; this can be seen graphically in Fig. 2, where we plot α vs g_A/g_V for $\beta = 1$.

The axial-vector and vector baryon currents are assumed in Cabibbo's theory to transform as members of SU(3) octets. Further, $\Delta S = 0$ and $\Delta S = 1$ baryon currents are assumed members of the same octet but with different strengths given by

$$J_\lambda = \cos\theta\, J_\lambda(\Delta S = 0) + \sin\theta\, J_\lambda(\Delta S = 1), \qquad (4)$$

where J_λ stands for either axial-vector or vector currents. Here we assume that the Cabibbo angle θ is the same for the two currents. Both D-type (symmetrical) and F-type (antisymmetrical) SU(3) couplings contribute to the currents, and computation of the SU(3) coefficients yields, for the decay $\Sigma^- \to nl^-\bar{\nu}$, the axial-vector and vector-current coefficients $g_A = (D_A - F_A)\sin\theta$, $g_V = (D_V - F_V)\sin\theta$, respectively. From the hypothesis of conserved vector current, $F_V = 1$ and $D_V = 0$, so that $(g_A/g_V)_{\Sigma^-\to n} = F_A - D_A$.[8]

Willis et al.[2] obtained two best-fit solutions to all leptonic baryon decays. One of these, solution B, has since been excluded by a better measurement of the decay rate of $\Sigma^- \to \Lambda e^-\bar{\nu}$ by Barash et al.[9] Brene et al.,[10] and Carlson[11] have further investigated solution A. We have made a new fit to the data, with three parameters, θ, D_A, and F_A. A fit to the first six data points in Table I gives $g_A/g_V = 0.28$. That one of our experimental values that is in better accord with this, $g_A/g_V = 0.05^{+0.23}_{-0.32}$, agrees with the predicted value within one standard deviation. The best-fit values for all seven data points are $\theta = 0.258$, $D = -0.751$, and $F = -0.502$, yielding $g_A/g_V = 0.25$.

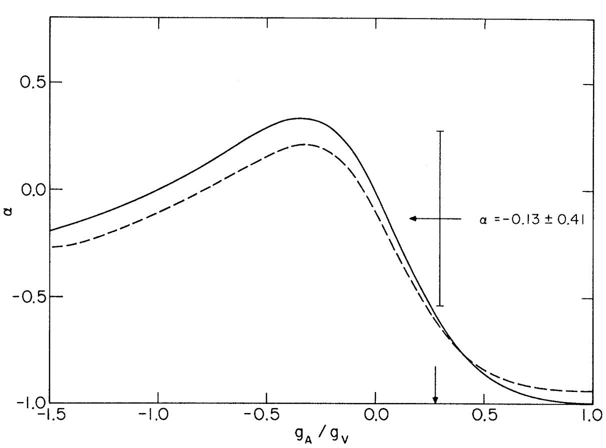

FIG. 2. Plot of α vs g_A/g_V for electrons. The solid curve is from Eq. (3); the dashed curve is from the more exact expression of Harrington for an electron momentum of 100 MeV/c. Our experimental value of α for electrons is indicated. The predicted value of g_A/g_V before this experiment was included is indicated by an arrow on the abscissa.

Table I. Data points used in determining best fit.

Decay	Branching ratio	Reference
$\Lambda \rightarrow p+e^{-}+\bar{\nu}$	$(8.8 \pm 1.5)\times 10^{-4}$	a
$\Sigma^{-} \rightarrow n+e^{-}+\bar{\nu}$	$(1.25 \pm 0.17)\times 10^{-3}$	a
$\Sigma^{-} \rightarrow \Lambda+e^{-}+\bar{\nu}$	$(6.4 \pm 1.2)\times 10^{-5}$	b
$\Xi^{-} \rightarrow \Lambda+e^{-}+\bar{\nu}$	$(1.0_{-0.65}^{+1.3})\times 10^{-3}$	c
Decay	g_A/g_V	Reference
$n \rightarrow p+e^{-}+\bar{\nu}$	-1.25 ± 0.04	d
$\Lambda \rightarrow p+e^{-}+\bar{\nu}$	$-1.14_{-0.33}^{+0.23}$	e
$\Sigma^{-} \rightarrow n+l^{-}+\bar{\nu}$	$0.05_{-0.32}^{+0.23}$	This work

[a]A. H. Rosenfeld, N. Barash-Schmidt, A. Barbaro-Galtieri, L. R. Price, P. Söding, C. G. Wohl, M. Roos, and W. J. Willis, Rev. Mod. Phys. 40, 77 (1968). The authors compile data from several experiments.

[b]Barash et al., Ref. 9.

[c]J. R. Hubbard, J. P. Berge, and P. M. Dauber, Phys. Rev. Letters 20, 465 (1968).

[d]G. Conforto, Acta Phys. Acad. Sci. Hung. 22, 15 (1967). This value of g_A/g_V is obtained from experiments involving free-neutron correlations. If one includes the determination from nuclear physics, a best value of -1.20 ± 0.02 is obtained. It is felt, however, that the free-neutron data are more reliable.

[e]G. Conforto, in Proceedings of the International School at Herceg-Novi, Yugoslavia, 1965, edited by M. Nikolić (Secretariat du Department de Physique Corpusculaire, Centre de Recherches Nucléaires, Strassbourg-Cronenbourg, France, 1965). This value is compiled from four experiments: V. G. Lind et al., Phys. Rev. 135, B1483 (1964); C. Baglin et al., Nuovo Cimento 35, 977 (1965); R. P. Ely et al., Phys. Rev. 137, B1302 (1965); J. Barlow et al., Phys. Letters 18, 64 (1965).

The χ^2 is 4.45, and the confidence level is 35%.

We are indebted to Dr. Joseph J. Murray for the creation of the K^- beam, and we acknowledge the encouragement of Professor Luis W. Alvarez. We also wish to thank the 25-in. bubble chamber crew and our scanners and measurers for their help.

*Work done under auspices of the U. S. Atomic Energy Commission.

[1]N. Cabibbo, Phys. Rev. Letters 10, 531 (1963).

[2]W. Willis et al., Phys. Rev. Letters 13, 291 (1964).

[3]R. Bangerter, A. Barbaro-Galtieri, J. P. Berge, J. J. Murray, F. T. Solmitz, M. L. Stevenson, and R. D. Tripp, Phys. Rev. Letters 17, 495 (1966); M. Watson, M. Ferro-Luzzi, and R. D. Tripp, Phys. Rev. 131, 2248 (1963).

[4]Events for which the Σ^- length is less than 1 mm are excluded to insure that all the events are indeed Σ^- decays.

[5]G. Källén, Elementary Particle Physics (Addison-Wesley Publishing Company, Inc., Reading, Mass., 1964), p. 361.

[6]We adopt the following notation: The Hamiltonian for leptonic baryon decay is $H=(G/\sqrt{2})J_\lambda l_\lambda$, where l_λ is the usual lepton current, $\bar{u}_e\gamma_\lambda(1+\gamma_5)u_\nu$, and $J_\lambda=V_\lambda+A_\lambda$ is the baryon current. With $V_\lambda=g_V\gamma_\lambda$ and $A_\lambda=-g_A\gamma_\lambda\gamma_5$, the baryon matrix element is then expressed as $\langle n|\gamma_\lambda(g_V-g_A\gamma_5)|\Sigma^-\rangle$. If time-reversal invariance is assumed, g_V and g_A are both real. Equation (3) neglects recoil effects and some terms involving the lepton mass. D. R. Harrington, Phys. Rev. 120, 1482 (1960), gives more exact expressions, but does not include energy dependence of the form factors.

[7]From the known branching ratio of $\Sigma^- \rightarrow \Lambda+e^-+\bar{\nu}$ there should be 1.4 events of that type in which the Λ decays neutrally. This contamination cannot seriously affect our results.

[8]To clarify conventions the corresponding expressions for neutron beta decay are $g_A=(D_A+F_A)\cos\theta$ and $g_V=(D_V+F_V)\cos\theta$, yielding $(g_A/g_V)_{n\rightarrow p}=D_A+F_A$.

[9]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).

[10]N. Brene, L. Veje, M. Roos, and C. Cronström, Phys. Rev. 149, 1288 (1966).

[11]C. Carlson, Phys. Rev. 152, 1433 (1966).

DETERMINATION OF COUPLING CONSTANTS FROM POLES IN SCATTERING CROSS SECTIONS*

R. E. Cutkosky and B. B. Deo†
Department of Physics, Carnegie-Mellon University, Pittsburgh, Pennsylvania
(Received 2 April 1968)

An optimally convergent polynomial expansion has been used in determining the residues of pion and $\Lambda+\Sigma$ poles from π-p and K^+-p differential scattering cross sections. A new method of conservatively estimating the uncertainty is also described.

The partial-wave expansion of a scattering amplitude $A(p, x=\cos\theta)$ only converges within an ellipse, and therefore does not exploit the full analyticity properties of A. Assuming A is analytic for x in a cut plane C, let us find a function $z(x)$ such that a polynomial expansion in z which is based on the physical region $-1 \leq x \leq 1$ will converge to A throughout C. According to the theory of polynomial approximation,[1] it is necessary and sufficient that $z(x)$ map the physical region