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Cabibbo's model with first-order SU_3-breaking corrections and hyperon β decay*

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We consider first-order symmetry-breaking corrections to Cabibbo's model and compare with available data on baryon semileptonic decays. The data seem to indicate that higher-order corrections are required, or else that second-class currents are present.

I. INTRODUCTION

The success with which Cabibbo's model[1] has met in the realm of semileptonic decays of hadrons shows that, beyond one's expectations, the SU_3-symmetry limit can be a very good approximation for these decays. The Ademollo-Gatto theorem[2] explains to a good extent why it should be so for the vector-current hadronic vertices, but no similar justification exists for the axial-vector-current ones. Therefore, the use of the symmetry limit for these vertices remains essentially a simplifying assumption within Cabibbo's model. Recently, new data in baryon semileptonic decays have become available. With the improvement of the experimental situation, it becomes interesting to find out to what extent the symmetry-limit approximation for the axial-vector current vertices is still valid. In an earlier analysis,[3] it became apparent that some symmetry-breaking corrections to Cabibbo's model, other than those due to the physical masses of the hyperons, seem to be required by the present data. In this paper we want to study the question of whether first-order symmetry-breaking corrections improve the agreement of Cabibbo's model with the data of hyperon semileptonic decays.

We shall assume that at the level of strong interactions SU_3 symmetry is broken by the eighth component of an octet. The interaction Hamiltonian is

$$\mathcal{H}_{\text{int}} = \mathcal{H}_0 + \epsilon \mathcal{H}_8 ,$$

where $\mathcal{H}_0$ is the invariant part and ϵ gives the relative magnitude between the two pieces. Assuming the weak-interaction hadronic currents to be related to the above Hamiltonian by Noether's theorem, then they no longer transform as pure octets. An expansion to first order in ϵ of the matrix elements of such currents between states which belong to octets has been given by Ademollo and Gatto.[2] If the currents are first class[4] in the symmetry limit, then second-class contributions to the amplitudes will be induced by symmetry breaking.[5] The presence of such terms can be important for improving agreement with the data.[6,7] We shall assume that only first-order corrections are present. Therefore, in accordance with the Ademollo-Gatto theorem, and because the variation range of the momentum transfer is small, we take the vector-current matrix elements at their symmetry-limit values, except for symmetry-breaking corrections due to the values of the hyperon physical masses. By use of the conserved-vector-current hypothesis[8] (CVC), the corresponding reduced matrix elements are fixed in terms of the electric charges and magnetic dipole moments of the nucleons. Only the axial-vector-current amplitudes are corrected to first order. We use the respective reduced matrix elements as free parameters to fit the available experimental rates and angular coefficients. In Sec. II we give the expansion up to first order in symmetry breaking of the hadronic part of the axial-vector-current amplitudes, as well as the expressions of the different form factors in terms of reduced matrix elements. In Sec. III the results of different fits are displayed. In Sec. IV, we discuss whether these results can be reconciled with small symmetry-breaking corrections. There we also compare them with a recent calculation of the pseudotensor form factors by Pritchett and Deshpande.[9] In Sec. V, we study the sensitivity of our results to the present experimental situation. We reserve Sec. VI for some final comments.

II. FIRST-ORDER CORRECTIONS

We shall incorporate first-order symmetry-breaking corrections in Cabibbo's model by using the expansion of the hadronic part of the weak transition amplitudes given by Ademollo and Gatto in Ref. 2. In order to state our conventions and notation we briefly review this expansion. Between states B that belong to octets, the matrix elements of a current are given by

$$a_0 \mathrm{Tr}(\bar{B}B\lambda_i) + b_0 \mathrm{Tr}(\bar{B}\lambda_i B) + a\,\mathrm{Tr}(\bar{B}B\{\lambda_i, \lambda_8\}) + b\,\mathrm{Tr}(\bar{B}\{\lambda_i, \lambda_8\}B) + c[\mathrm{Tr}(\bar{B}\lambda_i B\lambda_8) - \mathrm{Tr}(\bar{B}\lambda_8 B\lambda_i)] + g\,\mathrm{Tr}(\bar{B}B)\mathrm{Tr}(\lambda_i\lambda_8) + h[\mathrm{Tr}(\bar{B}\lambda_i)\mathrm{Tr}(B\lambda_8) + \mathrm{Tr}(\bar{B}\lambda_8)\mathrm{Tr}(B\lambda_i)] \quad (1)$$

and

$$a_1 \mathrm{Tr}(\bar{B}B[\lambda_i, \lambda_8]) + b_1 \mathrm{Tr}(\bar{B}[\lambda_i, \lambda_8]B) + h_1[\mathrm{Tr}(\bar{B}\lambda_i)\mathrm{Tr}(B\lambda_8) - \mathrm{Tr}(\bar{B}\lambda_8)\mathrm{Tr}(B\lambda_i)] , \quad (2)$$

where i is the SU_3 index of the current, and $a_0, b_0, \ldots, h_1$ are reduced matrix elements. For first-order symmetry-breaking corrections, λ_8 can only appear linearly. The reduced matrix elements $a, b, \ldots, h_1$ are expected to be of the order of magnitude of the parameter ϵ that gives the relative size between the invariant piece $\mathcal{H}_0$ in the strong-interaction Hamiltonian and the piece $\mathcal{H}_8$ which breaks the symmetry. a_0 and b_0 are related to the usual symmetric and antisymmetric reduced matrix elements f and d by

$$a_0 = -f + d ,$$

$$b_0 = f + d .$$

In terms of form factors, the weak hadronic vertices for semileptonic hyperon decay $A \to Bl\nu$ in Cabibbo's model are given by

$$\langle B|j_\mu^V|A\rangle = T(\theta)\left(\frac{m_A m_B}{E_A E_B}\right)^{1/2} \bar{u}(p_B)\left[f_1^{AB}(q^2)\gamma_\mu + f_2^{AB}(q^2)\frac{\sigma_{\mu\nu}}{m_A} q_\nu + f_3^{AB}(q^2)\frac{q_\mu}{m_A}\right] u(p_A) \quad (3)$$

and

$$\langle B|j_\mu^A|A\rangle = T(\theta)\left(\frac{m_A m_B}{E_A E_B}\right)^{1/2} \bar{u}(p_B)\left[g_1^{AB}(q^2)\gamma_\mu + g_2^{AB}(q^2)\frac{\sigma_{\mu\nu}}{m_A} q_\nu + g_3^{AB}(q^2)\frac{q_\mu}{m_A}\right]\gamma_5 u(p_A) , \quad (4)$$

where $T(\theta)$ is $\cos\theta$ or $\sin\theta$ for $\Delta S = 0$ or $\Delta S = 1$ decays, θ is the Cabibbo angle, and $q^2 = (p_A - p_B)^2$ is the invariant-momentum transfer. For transitions within the same isotopic multiplet, the different form factors can be classified under G parity if the currents have definite transformation properties under G, namely[4]

$$G j_\mu^V G^{-1} = \pm j_\mu^V$$

and (5)

$$G j_\mu^A G^{-1} = \mp j_\mu^A .$$

The upper signs correspond to first-class currents and the lower signs to second-class currents. For strangeness-changing decays, a similar classification can be made[5] under $G' = Ce^{-i\pi V_2}$, C being the charge conjugation operator and V_2 the second component of V spin. For first-class currents, only f_1, f_2 and g_1, g_3 can be nonzero, and for second-class currents only f_3 and g_2 contribute. Since the electromagnetic current is first class, the CVC hypothesis requires f_3 to be zero. Cabibbo's model assumes that the axial-vector current is also first class. But g_2 terms could be present in decays between different isomultiplets when SU_3 is broken.

The expansions (1) and (2) to first-order symmetry breaking correspond to first- and second-class amplitudes, respectively. In terms of the reduced matrix elements that appear there, the axial-vector form factors in the decays which are of interest to us are given as

$$g_1^{np}(q^2) = b_0 + \frac{2}{\sqrt{3}}(b - c) ,$$

$$g^{\Sigma^\pm\Lambda}(q^2) = \frac{6}{\sqrt{6}}\left[a_0 + b_0 + \frac{2}{\sqrt{3}}(a + b + 3h)\right] ,$$

$$g_1^{\Lambda p}(q^2) = \frac{1}{\sqrt{6}}\left[a_0 - 2b_0 + \frac{1}{\sqrt{3}}(-a + 2b + 3c + 6h)\right] ,$$

$$g_1^{\Sigma^- n}(q^2) = a_0 - \frac{1}{\sqrt{3}}(a + c) , \quad (6)$$

$$g_1^{\Xi^-\Lambda}(q^2) = \frac{1}{\sqrt{6}}\left[-2a_0 + b_0 + \frac{1}{\sqrt{3}}(2a - b - 3c + 6h)\right] ,$$

$$g_1^{\Xi^-\Sigma^0}(q^2) = \frac{1}{\sqrt{2}}\left[b_0 + \frac{1}{\sqrt{3}}(-b + c)\right]$$

and

$$g_2^{np}(q^2) = 0 ,$$

$$g_2^{\Sigma^\pm\Lambda}(q^2) = -\sqrt{2}\, h_1 ,$$

$$g_2^{\Lambda p}(q^2) = \sqrt{2}\,(-\tfrac{1}{2}a_1 + b_1 + h_1) ,$$

$$g_2^{\Sigma^- n}(q^2) = -\sqrt{3}\, a_1 , \quad (7)$$

$$g_2^{\Xi^-\Lambda}(q^2) = \sqrt{2}\,(a_1 - \tfrac{1}{2}b_1 - h_1) ,$$

$$g_2^{\Xi^-\Sigma^0}(q^2) = -(\tfrac{3}{2})^{1/2} b_1 .$$

A complete and very clear discussion of the foregoing was given by Gatto in Ref. 10. Notice that there a different convention from that of Ref. 2 is used to state which are the independent reduced matrix elements in Eqs. (1) and (2). From Eqs. (7) it can be seen that in the symmetry limit the second-class pseudotensor form factors vanish.[5] The $f_1(0)$ in the vector vertices are not corrected to first-order symmetry breaking.[2] In defining a dimensionless $f_2(0)$, a definite prescription of symmetry breaking is implied.[8] Once such a prescription is adopted, the dimensionless $f_2(0)$ is assumed to obey the Ademollo-Gatto theorem. Unfortunately, the contribution of $f_2(0)$ to the experimental quantities is quite small and it is not very relevant which convention is chosen. Inasmuch as one expects the breaking of SU_3 to be small, and the range of q^2 variation being small, the reduced form factors in $f_1(q^2)$ and $f_2(q^2)$ can be fixed in terms of the charges and magnetic moments of the nucleons[11] by the use of CVC.

For later comparison, we quote in Table I the values of the axial-vector form factors which the Cabibbo model predicts[3] in the exact SU_3 limit. The corresponding values of f, d, and θ are

$$f=0.466\pm0.009\,,\quad d=0.809\pm0.009\,,\quad \theta=0.236\pm0.004\,. \tag{8}$$

III. COMPARISON WITH THE DATA

The reduced form factors which appear in Eqs. (6) and (7) can be used as free parameters to fit the experimental data in hyperon semileptonic decays. The q^2 dependence of the different form factors can be parametrized linearly.[12] The contributions of the slopes to the decay rates and angular correlation coefficients will be at most second order in the parameter $\beta=(m_A-m_B)/m_A$. Therefore, such contributions will be much suppressed so as to detect any small difference (due to symmetry breaking) between the different slopes. We follow the parametrization of the slopes proposed in Ref. 12. Thus, except for ratios of squared masses, we take a common slope for the vector form factors $f_1(q^2)$ corresponding to the dipole formula for the electromagnetic form factors of the nucleons. For the axial-vector form factors we take, again except for ratios of squared masses, a common slope corresponding to the dominance of some axial-vector meson pole of average mass.[12] Any small differences in the slopes, due to symmetry breaking, again go undetected. The q^2 dependence of the induced tensor and pseudotensor $f_2(q^2)$ and $g_2(q^2)$ need not be considered, since it would contribute at most in third order in β. The pseudoscalar form factor $g_3(q^2)$ can be present in the muon decay modes. Assuming the validity of PCAC (partial conservation of axial-vector current), $g_3(q^2)$ can be related to $g_1(q^2)$. We use PCAC as proposed by Nieh.[13]

The experimental numbers we shall use are displayed in Table II. The theoretical expressions for the rates and angular coefficients are from Refs. 7, 12, and 14. It is to be expected that, since the number of parameters is large (nine reduced matrix elements plus the Cabibbo angle), the data will most likely be well fitted. But, what we want to find out is whether the values of the parameters and of the $g_1(0)$ and $g_2(0)$ form factors obtained can be interpreted as corresponding to small symmetry-breaking corrections. We cannot keep f and d (the symmetry-limit reduced matrix elements) and θ fixed at the values of Eqs. (8), since these values were obtained from the data itself; however, we expect their new values to remain close to Eqs. (8). Otherwise, it would not be consistent with small symmetry-breaking corrections.

Performing a χ^2 fit to the data in Table II, several fits are obtained. We have selected that with the lowest χ^2 and the values of f, d, and θ closest to Eqs. (8). The values obtained for the parameters are given in Table III. The other fits all changed f and d by large amounts from Eqs. (8), and, also, some of the symmetry-breaking reduced form factors were fixed at values two or

TABLE I. Values of the form factors of Eqs. (6) and (7) predicted by Cabibbo's model in the exact SU_3 limit, from Ref. 3.

Decay	g_1	g_1/f_1	g_2
np	1.275	1.275	0
$\Sigma^-\Lambda$	0.661	∞	0
$\Sigma^+\Lambda$	0.661	∞	0
Λp	−0.901	0.736	0
Σ^-n	0.343	−0.343	0
$\Xi^-\Lambda$	0.241	0.197	0
$\Xi^-\Sigma^0$	0.902	1.275	0

TABLE II. Experimental rates and angular coefficients. The transition rates are in units of 10^6 sec^{-1}, except for $n\to pe^-\bar\nu$, which is in 10^{-3} sec^{-1}. References to the sources of these data are given in Ref. 3. $\alpha_{e\nu}$ means electron-neutrino angular correlation coefficient, α_e electron asymmetry with respect to the spin of the decaying baryon, etc.

Rates		Angular coefficients		
np	1.070 ± 0.016	np	$\alpha_{e\nu}$	-0.095 ± 0.028
Λp	3.353 ± 0.139	np	α_e	-0.116 ± 0.007
$\Sigma^+\Lambda$	0.252 ± 0.059	np	α_ν	1.001 ± 0.038
$\Sigma^-\Lambda$	0.407 ± 0.040	Λp	$\alpha_{e\nu}$	0.007 ± 0.037
Σ^-n	7.385 ± 0.325	Λp	α_e	0.13 ± 0.06
$\Xi^-\Lambda$	6.928 ± 5.404	Λp	α_ν	0.82 ± 0.06
$\Xi^-\Lambda,\Sigma^0$	$3.735^{+1.206}_{-1.808}$	Λp	α_p	-0.51 ± 0.07
$\Lambda p\mu$	0.643 ± 0.138	Σ^-n	$\alpha_{e\nu}$	0.42 ± 0.25
$\Sigma^-n\mu$	3.012 ± 0.289	Σ^-n	α_e	0.04 ± 0.30
		$\Sigma^\pm\Lambda$	$\alpha_{e\nu}$	-0.40 ± 0.18

TABLE III. Values of the parameters of Eqs. (6) and (7) which give the best fit to the data in Table II.

f	0.447 ± 0.009	a_1	-0.849 ± 0.130
d	0.724 ± 0.009	b_1	0.428 ± 0.110
a	0.064 ± 0.047	h_1	-0.229 ± 0.107
b	0.396 ± 0.009	θ	0.264 ± 0.004
c	0.294 ± 0.008	n_D	9
h	-0.118 ± 0.013	χ^2	12.05

TABLE IV. Values of the different form factors for the fit of Table III. These numbers should be compared with those in Table I.

Decay	g_1	g_1/f_1	g_2
np	1.289 ± 0.018	1.289 ± 0.020	0
$\Sigma^-\Lambda$	0.645 ± 0.029	∞	0.324 ± 0.150
$\Sigma^+\Lambda$	0.645 ± 0.029	∞	0.324 ± 0.150
Λp	0.630 ± 0.025	0.515 ± 0.021	0.882 ± 0.238
$\Sigma^- n$	0.071 ± 0.026	−0.071 ± 0.030	1.470 ± 0.223
$\Xi^-\Lambda$	−0.187 ± 0.031	−0.153 ± 0.026	−1.179 ± 0.253
$\Xi^-\Sigma_0$	0.787 ± 0.011	1.113 ± 0.014	−0.525 ± 0.135

three times larger than that of the largest magnitude between f and d. We have estimated the error bars in Table III as those which represent one standard deviation along each coordinate from the $\chi^2_{\min}$ point. The predicted values for the different form factors are given in Table IV, and the predicted rates and angular coefficients are shown in Table V.

Before closing this section, we should like to consider another possibility at hand. The formulation of universality by Cabibbo does not imply that there is one common angle for vector and axial-vector currents.[8] Since we have already included the renormalization of the hadronic vertices due to SU_3 breaking, any difference between a vector angle θ_V and an axial-vector one θ_A should be attributed to the breaking of a higher symmetry or to an instrinsic weak effect. If this possibility is considered, the number of solutions grows. The effect of the second angle is to allow the parameters to have values scattered over a wider range than in the one-angle case. The χ^2 was lowered slightly, but most of the solutions again had one or several of the symmetry-breaking parameters larger than the largest of f or d by a factor of 2 or more: What can be considered the best fit is

TABLE V. Values for the rates and angular coefficients corresponding to the fit in Table III. The rates are in units of 10^6 sec^{-1}, except for $n \to pe^-\bar{\nu}$, which is in 10^{-3} sec^{-1}. These numbers should be compared with the experimental ones in Table II.

Rates		Angular coefficients		
np	1.054	np	$\alpha_{e\nu}$	−0.111
Λp	3.329	np	α_e	−0.125
$\Sigma^+\Lambda$	0.247	np	α_ν	0.986
$\Sigma^-\Lambda$	0.409	Λp	$\alpha_{e\nu}$	0.021
$\Sigma^- n$	7.151	Λp	α_e	0.024
$\Xi^-\Lambda$	3.503	Λp	α_ν	0.921
$\Xi^-\Lambda, \Sigma^0$	4.087	Λp	α_p	−0.553
$\Lambda p\mu$	0.567	$\Sigma^- n$	$\alpha_{e\nu}$	0.491
$\Sigma^- n\mu$	3.420	$\Sigma^- n$	α_e	0.023
		$\Sigma^\pm\Lambda$	$\alpha_{e\nu}$	−0.404

TABLE VI. Values of the parameters when different vector and axial-vector Cabibbo angles are assumed.

f	0.357 ± 0.010	b_1	3.804 ± 0.310
d	0.729 ± 0.009	h_1	−0.240 ± 0.250
a	1.893 ± 0.059	θ_V	0.261 ± 0.003
b	0.471 ± 0.008	θ_A	0.093 ± 0.005
c	0.330 ± 0.009	n_D	8
h	−0.768 ± 0.019	χ^2	11.63
a_1	4.040 ± 0.430		

displayed in Table VI. In Table VII, the corresponding axial-vector and pseudotensor form factors are given. For g_1/f_1 and g_2 we quote different sets of values, those independent of the angles and those where they are multiplied by $\cos\theta_A/\cos\theta_V$, or $\sin\theta_A/\sin\theta_V$, as applicable. The latter are marked with a prime. The predicted values for the rates and angular coefficients agree with those of Table V up to small changes of at most 1%, except $\alpha_e^{\Sigma^- n}$, which changes to 0.171, and the $\Xi^- \to \Lambda e^-\bar{\nu}$ rate, which changes to 4.028×10^6 sec^{-1}.

IV. DISCUSSION

We should now like to discuss the results of Sec. III. Comparing Tables V and II, the predicted rates and angular coefficients are in over-all good agreement, better than the case when the exact SU_3 limit is assumed.[3] The electron asymmetry in $\Sigma^- \to ne^-\bar{\nu}$ decay is considerably different from the symmetry-limit prediction of −0.70. The neutrino asymmetry in $\Lambda \to pe^-\bar{\nu}$ is still not within error bars, but it has been lowered into better agreement. If we now look at Tables III and VI, we find that the symmetry-limit parameters are more or less close to Eqs. (8), but some of the symmetry-breaking parameters are large. a_1 in Table III has about the same magnitude as d. In Table VI, a_1, b_1, and a are several times larger than d. In this respect, the second angle θ_A brings no improvement. Equations (6) and (7) are acceptable as long as the parameter ϵ, which is meant to give

TABLE VII. Axial-vector and pseudotensor form-factor values corresponding to the two-angle fit of Table VI. The primes in the last two columns indicate that factors $\cos\theta_A/\cos\theta_V$ or $\sin\theta_A/\sin\theta_V$, as applicable, have been included.

Decay	g_1	g_1/f_1	g_2	$(g_1/f_1)'$	g_2'
np	1.250	1.250	0	1.289	0
$\Sigma^-\Lambda$	0.623	∞	0.339	∞	0.642
$\Sigma^+\Lambda$	0.623	∞	0.339	∞	0.642
Λp	−1.813	1.480	2.185	−0.537	0.647
$\Sigma^- n$	−0.911	0.911	−6.997	−0.270	−2.073
$\Xi^-\Lambda$	−0.399	−0.326	3.361	−0.118	0.996
$\Xi^-\Sigma_0$	0.710	1.004	−4.660	0.210	−1.380

the order of magnitude of symmetry-breaking contributions, can be handled to first order. A 20% estimate for ϵ sounds reasonable, as is the case for the Gell-Mann–Okubo mass formula.[15] If we accept this criterion, then we can discard the solution for different θ_V and θ_A. The one-angle solution, though better, is still hard to accept. If, instead, we look into Tables IV and VII, we see that the induced pseudotensor form factors are comparable to the axial-vector ones. Here we see another reason why the two-angle hypothesis is of no help. Once g_1 and g_2 are corrected by the fact that there are two angles, i.e., into $g_{1,2}T(\theta_A)/T(\theta_V)$, the numbers obtained are almost the same as in Table IV. It should be noted that the neutron parameters are already under stress. The value of g_1/f_1 from neutron asymmetries[16] is 1.252 ± 0.014, and the Cabibbo angle from K-meson decays[17] is $\sin\theta = 0.221 \pm 0.004$. Before drawing conclusions, it is necessary to compare with a theoretical calculation of g_2.

Pritchett and Deshpande[9] have calculated the pseudotensor terms in $\Lambda \to pe^-\bar{\nu}$, $\Sigma^- \to ne^-\bar{\nu}$, and $\Sigma^\pm \to \Lambda e^\pm \nu$ decays, induced by the breaking of SU_3. Their calculation is based on dispersion relations assuming that lowest mass intermediate states dominate and implicitly assuming that, except for the mass breaking, other breakings are in some sense due to first-order corrections. They give the following estimates:

$$g_2^{\Lambda p} = 0.027 \pm 0.080 ,$$
$$g_2^{\Sigma^- n} = -0.112 \pm 0.056 , \qquad (9)$$
$$g_2^{\Sigma^\pm \Lambda} = 0.311 \pm 0.077 .$$

In (9) we have corrected the values of Pritchett and Deshpande for different normalization of g_2. They define a dimensionless g_2 by dividing in Eq. (4) by $m_A + m_B$, while we divide by m_A only. Our convention is such that it allows the symmetry-breaking parameters in (7) to be smaller. If we use their convention, then the values of a_1, b_1, and h_1 in Tables III and VI would be twice as large. The above values are uncertain[9] to the extent that they could change because of a conspiracy of the breaking in SU_3 couplings or because of an enhancement of one of the intermediate states due to a resonance effect. Therefore, the authors recommend that one look at the values (9) with a tolerance up to three standard deviations. In this respect, we should also be cautious with the error bars for g_2 in Table IV. Those quoted there are not true standard deviations, because there is surely correlation of errors. In order to estimate what the true errors can be, we can look, for example in the case of $\Lambda\beta$ decay, at the contours $\chi^2 = \chi^2_{\min} + 1$ given in Ref. 7, although these contours correspond to more relaxed data. It is seen there that the error in $g_2^{\Lambda p}$ can be two to three times that quoted in Table IV. This would also make the errors in $g_2^{\Sigma\Lambda}$ and $g_2^{\Sigma n}$ grow accordingly. Therefore, we should allow for errors two to three times larger than those of Table IV. With these considerations in mind, we can see from Eqs. (9) and Table IV that the values we obtained for g_2 are quite separate in $\Sigma^- \to ne\nu$ and $\Lambda \to pe\nu$ from those expected on the basis of first-order symmetry breaking.

V. SENSITIVITY OF THE RESULTS TO THE PRESENT DATA

Unfortunately, the present experimental situation in hyperon β decay is not yet solidly established. Therefore we must exercise care in drawing conclusions. It should be interesting to see how sensitive our results are to the present data. Particularly so, in view that our conclusions rely heavily on the present experimental values of the spin asymmetries in $\Lambda \to pe\nu$ and $\Sigma^- \to ne\nu$ decays. The asymmetries in $\Lambda \to pe\nu$ have been recently measured with improved statistics in two different experiments, one by a CERN-Heidelberg collaboration (Althoff *et al.*) and another one by an Argonne-Chicago-Ohio-Washington collaboration (Lindquist *et al.*).[3] The first experiment seems to be in better agreement with the simple Cabibbo model, while the second one shows some deviations from it. The electron asymmetry in $\Sigma^- \to ne\nu$ still has large error bars. At present, a small positive value is

TABLE VIII. Values of the parameters of Eqs. (6) and (7) and of the asymmetries in $\Lambda \to pe\nu$ and $\Sigma^- \to ne\nu$ when only the data of Althoff *et al.* for the Λp spin asymmetries are used (column I), and when only the data of Lindquist *et al.* for these quantities are used (column II).

	I	II
f	0.484 ± 0.009	0.450 ± 0.009
d	0.754 ± 0.009	0.725 ± 0.009
a	0.051 ± 0.045	0.054 ± 0.047
b	0.379 ± 0.008	0.403 ± 0.009
c	0.336 ± 0.008	0.305 ± 0.008
h	-0.125 ± 0.013	-0.118 ± 0.013
a_1	-0.886 ± 0.121	-0.857 ± 0.129
b_1	0.299 ± 0.116	0.511 ± 0.114
h_1	-0.232 ± 0.112	-0.230 ± 0.111
θ	0.260 ± 0.004	0.264 ± 0.004
n_D	9	9
χ^2	9.48	9.91
Λp $\alpha_{e\nu}$	0.012	0.007
Λp α_e	0.027	0.013
Λp α_ν	0.937	0.918
Λp α_p	−0.566	−0.545
$\Sigma^- n$ $\alpha_{e\nu}$	0.432	0.483
$\Sigma^- n$ α_e	0.049	0.026

TABLE IX. Axial-vector and pseudotensor form-factor values corresponding to the fit of Table VIII. The column labels I and II correspond to the data of Althoff *et al.* and of Lindquist *et al.*, respectively.

	I		II	
	g_1	g_2	g_1	g_2
np	1.288 ± 0.018	0	1.289 ± 0.018	0
$\Sigma^{\pm}\Lambda$	0.641 ± 0.029	0.329 ± 0.153	0.642 ± 0.029	0.325 ± 0.157
Λp	-0.674 ± 0.025	0.721 ± 0.237	-0.621 ± 0.025	1.003 ± 0.240
$\Sigma^- n$	0.046 ± 0.026	1.534 ± 0.219	0.068 ± 0.026	1.484 ± 0.223
$\Xi^-\Lambda$	-0.195 ± 0.031	-1.136 ± 0.253	-0.196 ± 0.031	-1.248 ± 0.255
$\Xi^-\Sigma_0$	0.858 ± 0.011	-0.367 ± 0.133	0.791 ± 0.011	-0.626 ± 0.137

favored by experiments, and this contrasts with Cabibbo's model prediction of a large negative one. In order to test the sensitivity of our results to this situation, we propose to repeat the fits of Sec. III, first using for the Λ spin asymmetries the values of Althoff *et al.* only and leaving out those of Lindquist *et al.* and then the reversed alternative, using those of Lindquist *et al.* only, leaving out those of Althoff *et al.* Finally, we study what are the predictions for $\Sigma^- \to ne\nu$ angular coefficients. For this, we repeat the fits without including the experimental values of the e asymmetry and the $e\nu$ angular correlation in this decay. We also allow for the above alternatives in using the data of Λ decay. We restrict ourselves to the one-angle case, which, as seen in Sec. IV, merits more attention.

In Tables VIII and IX are displayed the results of fitting, alternatively, using only the data of Althoff *et al.* or only the data of Lindquist *et al.* for the Λ spin asymmetries. We have only reproduced the values of Λp and Σn angular-correlation coefficients. All other measurable quantities remained practically at the same values they had in Table V. In comparing these new tables with Tables III, IV, and V, we see that no substantial change is obtained. Therefore, the same comments of Sec. IV apply here. The only effect of having allowed variations in the Λp data is a change in the value of χ^2. This is mainly caused by the more relaxed error bars each set of data has compared to the set of average values.

As mentioned just above, in order to test the sensitivity of our results to the $\Sigma^- n$ asymmetries, we have repeated the fits without including their experimental values. The results are shown in Tables X and XI. We have considered three alternatives for the experimental values of the Λ spin asymmetries. First, the data of Althoff *et al.* were used, then the data of Lindquist *et al.* were used, and finally their present average values were used. Comparing Tables X and XI with Tables III, IV, and V, it can be seen that the in-

TABLE X. These are the results when the fits are repeated excluding the experimental values of $\alpha_{e\nu}$ and α_e in $\Sigma^- \to ne\nu$. Labels I, II, and III correspond to the data of Althoff *et al.*, Lindquist *et al.*, and the averaged data for the Λ spin asymmetries, respectively.

	I	II	III
f	0.359 ± 0.009	0.382 ± 0.009	0.357 ± 0.009
d	0.913 ± 0.009	0.882 ± 0.009	0.913 ± 0.009
a	-0.079 ± 0.045	-0.114 ± 0.046	-0.008 ± 0.045
b	0.178 ± 0.009	0.212 ± 0.009	0.182 ± 0.008
c	0.167 ± 0.008	0.192 ± 0.008	0.169 ± 0.008
h	-0.108 ± 0.013	-0.089 ± 0.013	-0.106 ± 0.013
a_1	-1.408 ± 0.226	-1.286 ± 0.223	-1.439 ± 0.222
b_1	-0.168 ± 0.119	0.084 ± 0.118	-0.144 ± 0.116
h_1	-0.238 ± 0.114	-0.238 ± 0.114	-0.248 ± 0.112
θ	0.252 ± 0.004	0.257 ± 0.004	0.252 ± 0.004
n_D	7	7	7
χ^2	7.89	8.66	11.41
$\Lambda p\ \alpha_{e\nu}$	0.007	0.003	0.008
$\Lambda p\ \alpha_e$	0.034	0.024	0.033
$\Lambda p\ \alpha_\nu$	0.959	0.943	0.955
$\Lambda p\ \alpha_p$	-0.587	-0.569	-0.584
$np\ g_1$	1.286	1.287	1.285
$\Sigma^{\pm}\Lambda\ g_1$	0.640	0.641	0.641
$\Lambda p\ g_1$	-0.744	-0.691	-0.734
$\Xi^-\Lambda\ g_1$	-0.282	-0.257	-0.289
$\Xi^-\Sigma_0\ g_1$	0.895	0.386	0.893
$\Sigma^{\pm}\Lambda\ g_2$	0.336	0.337	0.350
$\Lambda p\ g_2$	0.422	0.691	0.464
$\Xi^-\Lambda\ g_2$	-1.535	-1.540	-1.583
$\Xi^-\Sigma_0\ g_2$	0.206	-0.103	0.176

TABLE XI. Predicted values for the $\Sigma^- \to ne\nu$ decay angular correlations and axial-vector and pseudotensor form factors, from the fit of Table X. The experimental values of $\alpha_{e\nu}$ and α_e were not used in this fit.

$\Sigma^- n$	I	II	III
$\alpha_{e\nu}$	0.575	0.595	0.51
α_e	-0.723	-0.650	-0.731
g_1	0.503 ± 0.026	0.455 ± 0.026	0.509 ± 0.026
g_2	2.438 ± 0.391	2.227 ± 0.386	2.493 ± 0.385

terpretation of small symmetry breaking is rendered even more difficult when the data on α_e and $\alpha_{e\nu}$ of $\Sigma^- n$ are excluded. Curiously enough, α_e is predicted to be at its symmetry-limit value, although $\alpha_{e\nu}$ is now put at a somewhat different value. But the g_2 form factor is now predicted to be even larger.

The above analysis puts us in a better position to judge our results. They seem to be stable to small variations in the Λ spin asymmetries data. When the data on Σ^- asymmetries are excluded, α_e is predicted to be large and negative. So, if such a value is experimentally confirmed but the Λ data happen to sit where they are now, or even if the situation is somewhat less radical, then stronger symmetry breaking seems to be favored.

VI. FINAL COMMENTS

Our main conclusion is that the present data seem to indicate that if one wants to improve Cabibbo's model for baryon semileptonic decays by including symmetry-breaking corrections alone, then these corrections must be stronger than small first-order corrections. If one were to take this point of view, one should then also correct the vector-current vertices. Nevertheless, there could be other alternatives. Since the second-class pseudotensor form factors turned out to be large, one might still be close to the symmetry limit if genuine second-class currents are present.[18]

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[1]N. Cabibbo, Phys. Rev. Lett. 10, 531 (1963); M. Gell-Mann and M. Lévy, Nuovo Cimento 16, 706 (1960); M. Gell-Mann, Physics 1, 63 (1964).

[2]M. Ademollo and R. Gatto, Phys. Rev. Lett. 13, 264 (1964); C. Bouchiat and Ph. Meyer, Nuovo Cimento 34, 1122 (1964).

[3]A. García, Phys. Rev. D 9, 177 (1974). In the present paper we use for the Λ spin asymmetries the experimental values published recently by R. Oehme, E. Swallow, and R. Winston, Phys. Rev. D 8, 2124 (1973). See this paper for references to the original experiments.

[4]S. Weinberg, Phys. Rev. 112, 1375 (1958).

[5]L. Wolfenstein, Phys. Rev. 135, B1436 (1964).

[6]R. Oehme, R. Winston, and A. García, Phys. Rev. D 3, 1618 (1971).

[7]A. García, Phys. Rev. D 3, 2638 (1971).

[8]For a review see, for example, R. E. Marshak, Riazuddin, and C. P. Ryan, *Theory of Weak Interactions in Particle Physics* (Wiley-Interscience, New York, 1969), and H. Pietschmann, in GIFT Lectures, Univ. of Zaragoza, Spain, 1972 (unpublished).

[9]P. L. Pritchett and N. G. Deshpande, Phys. Rev. D 8, 2963 (1973).

[10]R. Gatto, in *Symmetries in Elementary Particle Physics*, edited by A. Zichichi (Academic, New York, 1965).

[11]See, for example, R. Oehme, Ann. Phys. (N.Y.) 33, 108 (1965) for a review.

[12]I. Bender, V. Linke, and H. J. Rothe, Z. Phys. 212, 190 (1968).

[13]H. T. Nieh, Phys. Rev. 164, 1780 (1967).

[14]M. M. Nieto, Rev. Mod. Phys. 40, 140 (1968).

[15]See, for example, P. Carruthers, *Introduction to Unitary Symmetry* (Wiley, New York, 1967).

[16]H. Paul, Nucl. Phys. A154, 160 (1970).

[17]Quoted in R. J. Blin-Stoyle and J. M. Freeman, Nucl. Phys. A150, 369 (1970).

[18]R. Oehme, Phys. Lett. 38B, 532 (1972); H. Pietschmann, H. Stremnitzer, and U. E. Schroeder, Nuovo Cimento 15A, 21 (1973). These papers contain further references.