Fits of the hyperon-semileptonic-decay data and spectrum-generating SU(3). I

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A model of the current $\times$ current type for weak interactions has been formulated. The hadronic current is not of the Cabibbo type, but explicit SU(3) breaking by the mass operator is assumed to be present. The model also treats SU(3) as a spectrum-generating group. The predictions of the model for semileptonic decays of hyperons are compared with experimental data and with the predictions of the Cabibbo model.

I. INTRODUCTION

It is commonly believed that the conventional Cabibbo model[1] gives a very good fit of the hyperon-decay data.[2] Table I shows that this is indeed the case—especially after some radiative corrections have been taken into account—if one uses as experimental data the decay rates and the "experimental" g_A/g_V ratios, which are extracted from the experimental data under the assumption that all second-class contributions are zero. Table II shows the values for the asymmetries and correlation coefficients that are predicted by the Cabibbo model with the parameters from the fit in Table I. Comparing the predicted with the experimental values one discovers some discrepancies, the most glaring of which is probably the α_e for $\Sigma^- \to ne\nu$. It is also the most interesting, since the analysis of a recent experiment will soon be completed and preliminary results indicate that the new value of $\alpha_e^{\Sigma n}$, obtained with much higher statistics than the old world average in Table II, will definitely be positive.[3] From a theoretical point of view $\alpha_e^{\Sigma n}$ is also very interesting, because an induced second-class contribution in the weak current that is proportional to the mass difference will effect this quantity more than the other precisely measured experimental values.

TABLE I. Fit of the Cabibbo model to the experimental decay rates and experimental g_A/g_V ratios. With 10 degrees of freedom the confidence level is 0.01 without radiative corrections and 0.305 with radiative corrections. In both cases $\sin\theta \approx 0.230$.

Process	Experimental value (sec^{-1})	Cabibbo model: Predicted value (sec^{-1})	Cabibbo model: Contribution to χ^2	Cabibbo model with radiative corrections: Predicted value (sec^{-1})	Cabibbo model with radiative corrections: Contribution to χ^2
$n \to pe\nu$ (rate)	$(1.091 \pm 0.017) \times 10^{-3}$	1.039×10^{-3}	9.222	1.077×10^{-3}	0.631
$\Sigma^+ \to \Lambda e\nu$ (rate)	$(0.253 \pm 0.059) \times 10^{6}$	0.294×10^{6}	0.479	0.292×10^{6}	0.429
$\Sigma^- \to \Lambda e\nu$ (rate)	$(0.412 \pm 0.034) \times 10^{6}$	0.487×10^{6}	4.825	0.483×10^{6}	4.372
$\Lambda \to pe\nu$ (rate)	$(3.066 \pm 0.109) \times 10^{6}$	3.059×10^{6}	0.004	3.081×10^{6}	0.019
$\Sigma^- \to ne\nu$ (rate)	$(7.287 \pm 0.275) \times 10^{6}$	7.148×10^{6}	0.256	7.161×10^{6}	0.209
$\Xi^- \to \Lambda e\nu$ (rate)	$(1.706 \pm 0.731) \times 10^{6}$	2.725×10^{6}	1.944	2.709×10^{6}	1.884
$\Xi^- \to (\Lambda\Sigma^0)e\nu$ (rate)	$(4.144 + 1.341) \times 10^{6}$	3.252×10^{6}	0.442	3.229×10^{6}	0.465
$\Lambda \to p\mu\nu$ (rate)	$(0.597 \pm 0.133) \times 10^{6}$	0.491×10^{6}	0.637	0.508×10^{6}	0.449
$\Sigma^- \to n\mu\nu$ (rate)	$(3.036 \pm 0.271) \times 10^{6}$	3.171×10^{6}	0.248	3.177×10^{6}	0.270
$n \to pe\nu$ (g_A/g_V)	1.254 ± 0.007	1.263	1.653	1.254	0.001
$\Lambda - pe\nu$ (g_A/g_V)	0.62 ± 0.05	0.705	2.867	0.698	2.431
$\Sigma^- \to ne\nu$ (g_A/g_V)	$\pm(0.435 \pm 0.035)$	-0.412	0.430	-0.415	0.342
$\Sigma^- \to \Lambda e\nu$ (g_V/g_A)	0.10 ± 0.22	0	0.207	0	0.207
Total χ^2			23.214		11.709

TABLE II. Predictions of the models of Table I for the asymmetries and correlation coefficients.

Process	Experimental value	Cabibbo model Predicted value	Cabibbo model Contribution to χ^2	Cabibbo model with radiative corrections Predicted value	Cabibbo model with radiative corrections Contribution to χ^2
$n\to pe\nu$ ($\alpha_{e\nu}$)	-0.074 ± 0.004	-0.077	0.634	-0.075	0.072
$n\to pe\nu$ (α_e)	-0.084 ± 0.003	-0.085	0.356	-0.083	0.074
$n\to pe\nu$ ($\alpha_{e\nu}$)	1.001 ± 0.038	0.988	0.117	0.989	0.105
$\Sigma^{\pm}\to\Lambda e\nu$ ($\alpha_{e\nu}$)	-0.400 ± 0.180	-0.400	0	-0.400	0
$\Sigma^-\to ne\nu$ ($\alpha_{e\nu}$)	0.280 ± 0.05	0.315	0.493	0.312	0.400
$\Sigma^-\to ne\nu$ (α_e)	0.040 ± 0.270	-0.711	7.730	-0.714	7.796
$\Lambda\to pe\nu$ (α_e)	0.125 ± 0.066	0.022	2.452	0.025	2.306
$\Lambda\to pe\nu$ ($\alpha_{e\nu}$)	0.036 ± 0.037	0.025	0.085	0.031	0.018
$\Lambda\to pe\nu$ (α_ν)	0.821 ± 0.060	0.975	6.583	0.973	6.453
$\Lambda\to pe\nu$ (α_p)	-0.508 ± 0.065	-0.580	1.243	-0.581	1.276

That the second-class, pseudovector contribution in hyperon decay may be large was first noticed by Garcia[4] when he investigated the process $\Lambda\to pe\bar{\nu}$ and it has recently again been confirmed by Adjei and Dicus[5] that already a fit to the present experimental data for this process $\Lambda\to pe\bar{\nu}$ alone requires a substantial g_2 term. Several hyperon-decay experiments are currently in progress[6] and it may be timely to reevaluate the situation from a theoretical and phenomenological point of view.

We shall, therefore, investigate here three general models[7]: the conventional Cabibbo model, the spectrum-generating-group (SG) model with Cabibbo current, and the SG model with a new current operator.[8] We will fit these models to 19 experimental data, i.e., the rates and the asymmetries and correlation coefficients. These fits for the first two models have been done before.[9,10] We have redone them here for the following reasons: (1) The experimental data have changed slightly. (2) In Refs. 9 and 10 approximations up to second order in $(m_B-m_{B'}/m_B$ were used for the α's; here we use the more exact theoretical expressions of Ref. 11, integrating numerically on the computer. (3) All the relevant formulas for the rates and asymmetries have been recalculated here independently of Refs. 9 and 10 and a different minimization program has been used for the χ^2 fit; our results therefore constitute a check of the calculations in Refs. 9 and 10.

In Sec. II we briefly state the relevant features of the two kinds of models. Section III describes the new ansatz for the current operator. Section IV discusses the fits and their results. In Sec. V we discuss the effect of radiative corrections, q^2 dependence of the form factor, and genuine second-class terms.

II. THE MODELS FOR SEMILEPTONIC DECAYS

The matrix elements of the SU(3) octet current V_μ^β, A_μ^β are given by

$$\langle p'\sigma'\alpha' \,|\, V_\mu^\beta + A_\mu^\beta \,|\, p\sigma\alpha\rangle = \bar{u}(p'\sigma')[f_1^{\alpha'\beta\alpha}(q^2)\gamma_\mu + f_2^{\alpha'\beta\alpha}(q^2) i\sigma_{\mu\nu}q^\nu + f_3^{\alpha'\beta\alpha}(q^2) q_\mu + g_1^{\alpha'\beta\alpha}(q^2)\gamma_\mu\gamma_5 + g_2^{\alpha'\beta\alpha}(q^2) i\sigma_{\mu\nu}q^\nu\gamma_5 + g_3^{\alpha'\beta\alpha}(q^2)\gamma_5 q_\mu] u(p\sigma) \,. \quad (1)$$

Here $q_\mu = p'_\mu - p_\mu$ is the momentum transfer between the baryons and α, α', and β denote the charge quantum numbers of the baryons and the currents. The form factors are given according to the conventional Cabibbo model by

$$f_i^{\alpha'\beta\alpha}(q^2) = \sum_{\gamma=1,2} C(\gamma;\alpha'\beta\alpha) f_i^\gamma(q^2) \,, \quad (2)$$

$$g_i^{\alpha'\beta\alpha}(q^2) = \sum_{\gamma=1,2} C(\gamma;\alpha'\beta\alpha) g_i^\gamma(q^2) \,. \quad (3)$$

f_i^1, g_i^1 are the F-type reduced matrix elements and f_i^2, g_i^2 are the D-type reduced matrix elements, and the q^2 dependence of these form factors is ignored. $C(\gamma;\alpha'\beta\alpha)$ are Clebsch-Gordan coefficients of the SU(3) group (we use the convention of Ref. 13).

An essential assumption in the derivation of Eqs. (2) and (3) is

$$[P_\mu, E_\alpha] = 0 \,, \quad (4)$$

where P_μ is the momentum operator and E_α are the generators of SU(3). Otherwise the Wigner-Eckart theorem cannot be applied. Experimentally Eq. (4) cannot hold since the SU(3) group is broken and masses are not constant within the multiplet. The equalities (2) and (3) are therefore only approximate and it is rather difficult to estimate their accuracy. This drawback was the motivation for the spectrum-generating-group approach[14] which assumes instead of (4) the relation[15]

$$[\hat{P}_\mu, E_\alpha]=0, \quad \hat{P}_\mu = M^{-1}P_\mu \; . \tag{5}$$

If (5) holds then not the momentum but the eigenvalue of $\hat{P}_\mu$, i.e., the four-velocity $\hat{p}_\mu = p_\mu / m(\alpha)$, is conveniently used as an additional label for the basis vectors in the hadron space. The matrix elements of the octet currents are then given by

$$\begin{aligned}\langle \hat{p}'\sigma'\alpha' \,|\, V_\mu^\beta + A_\mu^\beta \,|\, \hat{p}\sigma\alpha\rangle = (m_B m_{B'})^{3/2}\bar{u}(\hat{p}'\sigma')[\, & F_1^{\alpha'\beta\alpha}(\hat{q}^2)\gamma_\mu + F_2^{\alpha'\beta\alpha}(\hat{q}^2) i\sigma_{\mu\nu}\hat{q}^\nu + F_3^{\alpha'\beta\alpha}(\hat{q}^2)\hat{q}_\mu \\ & + G_1^{\alpha'\beta\alpha}(\hat{q}^2)\gamma_\mu\gamma_5 + G_2^{\alpha'\beta\alpha}(\hat{q}^2) i\sigma_{\mu\nu}\hat{q}^\nu\gamma_5 + G_3^{\alpha'\beta\alpha}(\hat{q}^2)\hat{q}_\mu\gamma_5]u(\hat{p}\sigma) \; .\end{aligned} \tag{6}$$

Here $\hat{q} = \hat{p}' - \hat{p}$ is the velocity transfer between the baryons and $|\hat{p}\sigma\alpha\rangle$ are the velocity eigenvectors; m_B and $m_{B'}$ are the baryon masses. The form factors $F_i^{\alpha'\beta\alpha}$ and $G_i^{\alpha'\beta\alpha}$ can be expressed in the following way:

$$F_i^{\alpha'\beta\alpha}(\hat{q}^2) = \sum_{\gamma=1,2} C(\gamma;\alpha'\beta\alpha) F_i^\gamma(\hat{q}^2) \; , \tag{7}$$

$$G_i^{\alpha'\beta\alpha}(\hat{q}^2) = \sum_{\gamma=1,2} C(\gamma;\alpha'\beta\alpha) G_i^\gamma(\hat{q}^2) \; , \tag{8}$$

where F_i^1, G_i^1 are the F-type and F_i^2, G_i^2 are the D-type reduced matrix elements. The equations (6), (7), and (8) are exact also if SU(3) symmetry is broken, and $F_i^\gamma(\hat{q}^2)$ and $G_i^\gamma(\hat{q}^2)$ are SU(3)-invariant form factors if only the Werle relation (5) holds. This is the advantage of the SG approach over the conventional model with broken SU(3) symmetry. (1), (2), and (3) can only be derived in the SU(3)-symmetry limit in which all the hadron masses are equal. To emphasize this obvious but generally ignored point again: it would require extraordinary cancellations to theoretically justify the conventional Cabibbo model as something more than an approximation if the hadron masses are not equal.

The transition matrix element for the semileptonic hyperon decay $B \to B' l \nu$ is given by

$$\begin{aligned} M = & \frac{G}{\sqrt{2}} \bar{u}_l(p_1)\gamma^\mu(1+\gamma_5)v_\nu(p_\nu) \\ & \times \langle \hat{p}'\sigma'\alpha' \,|\, J_\mu \,|\, \hat{p}\sigma\alpha\rangle \; , \end{aligned} \tag{9}$$

where J_μ is the weak-hadronic-current operator. For the conventional Cabibbo model one has instead of the velocity eigenvectors the usual momentum eigenvectors [note the mass factor in Eq. (6)].

The weak-hadronic-current operator in the conventional Cabibbo model and in the SG model of Ref. 10 is given in terms of the octet currents by

$$\begin{aligned} J_\mu = & \cos\theta_V V_\mu^{1+i2} + \cos\theta_A A_\mu^{1+i2} + \sin\theta_V V_\mu^{4+i5} \\ & + \sin\theta_A A_\mu^{4+i5} + \text{H.c.} \end{aligned} \tag{10}$$

For the SG model we always choose $\theta_V = \theta_A$; for the conventional model we shall also fit the data with two Cabibbo angles.

III. THE MULTICOMMUTATOR CURRENT OPERATOR

It has so far been considered essential that the suppression of the strangeness-changing decay should be given by (10) with $|\sin\theta| \approx \frac{1}{4}$. If the mass differences are taken seriously and the mass operator is not an SU(3) invariant, then there is another possible way the physical current can be expressed in terms of the octet current. The general principles for the construction of such an expression in the SG approach are the following[14]:

(1) J_μ is constructed from the SU(3) octet operators and the mass operator.

(2) In the limit of the exact symmetry [mass operator commuting with the SU(3) operators] the physical current goes into the octet current.

(3) The $V-A$ structure of the current is preserved.

(4) Universality.

In particular in (4) we assume that the strangeness-changing part of the current is not distinguished from the strangeness-conserving part, so in the limit of the exact symmetry the coupling constants for both parts of the current should be equal. In the symmetry limit the physical current becomes

$$J_\mu^S = V_\mu^{1+i2} + A_\mu^{1+i2} + V_\mu^{4+i5} + A_\mu^{4+i5} \ . \qquad (11)$$

The current J_μ^S is a good starting point for our construction. It is very easy to verify that the physical current J_μ constructed in the following way[8] from the current J_μ^S explicitly fulfills all assumptions (1)–(4):

$$J_\mu = J_\mu^S + B_1[M,J_\mu^S] + A_1[M,[M,J_\mu^S]] + B_2[M,[M,[M,J_\mu^S]]] + A_2[M,[M,[M,[M,J_\mu^S]]]] + \cdots \ . \qquad (12)$$

The square brackets in (12) denote commutators and $A_1, A_2, \ldots$ and $B_1, B_2, \ldots$ are phenomenological universal constants which do not depend on the type of the process. It is obvious that the current (12) fulfills all our four assumptions but it is not only ansatz for the physical current and it is quite easy to give alternative forms fulfilling all these assumptions.

Now we shall impose further conditions on the physical current in Eq. (12).

(i) Time-reversal invariance. From time-reversal invariance and the absence of the final-state interactions it follows[16] that all the form factors must be relatively real so all A_i and B_i must be real.

(ii) "Hermiticity." The Hermitian conjugate $J_\mu^\dagger$ of the current (12) is of the same importance as the current J_μ itself (e.g., if the process $\Sigma^- \to \Lambda e\nu$ is described by the current J_μ, then the process $\Sigma^+ \to \Lambda e\nu$ is described by the current $J^\dagger$). If we take the Hermitian conjugate of Eq. (12), then we obtain (A_i and B_i are real)

$$J_\mu^\dagger = J_\mu^{S\dagger} - B_1[M,J_\mu^{S\dagger}] + A_1[M,[M,J_\mu^{S\dagger}]] - B_2[M,[M,[M,J_\mu^{S\dagger}]]] + A_2[M,[M,[M,[M,J_\mu^{S\dagger}]]]] + \cdots \ . \qquad (13)$$

From Eq. (13) we thus see that the currents for $\Sigma^- \to \Lambda e\nu$ and $\Sigma^+ \to \Lambda e\nu$ would be constructed in a different way (the change of the sign of B_i's). In order to get the same functional dependence of J_μ and $J_\mu^\dagger$ on J_μ^S and $J_\mu^{S\dagger}$, we have to set $B_i = 0$.

In the following we shall confine ourselves to the case where only the first two terms do not vanish (i.e, only $A_1 \neq 0$ and $A_2 \neq 0$) and the final form of the physical current is given by the following expression:

$$J_\mu = J_\mu^S + A_1[M,[M,J_\mu^S]] + A_2[M,[M,[M,[M,J_\mu^S]]]] \ . \qquad (14)$$

The matrix elements of the current (14) are equal to

$$\langle \hat{p}'\sigma'\alpha' | J_\mu | \hat{p}\sigma\alpha \rangle = [1 + A_1(m_B - m_{B'})^2 + A_2(m_B - m_{B'})^4] \langle \hat{p}'\sigma'\alpha' | V_\mu^{1+i2} + A_\mu^{1+i2} + V_\mu^{4+i5} + A_\mu^{4+i5} | \hat{p}\sigma\alpha \rangle \ . \qquad (15)$$

This form of the matrix elements of the physical current will be used in the evaluation of the widths and the asymmetries for the semileptonic hyperon decays. Equation (14) exhibits a higher universality than the Cabibbo universality and explains the difference in the value of the coupling constant for decays between different states of the baryon octet by their mass differences. It explains the suppression as a symmetry-breaking effect expressed in terms of suppression factors $\phi_{B'B}$ which multiply the universal coupling constant and the Clebsch-Gordan coefficients. According to (14) the suppression factors are the following functions of the masses:

$$\phi_{B'B} = [1 + A_1(m_B - m_{B'})^2 + A_2(m_B - m_{B'})^4] \ , \qquad (16)$$

whereas in case (10) $\phi_{B'B}$ is given by

$$\phi_{B'B} = \begin{cases} \cos\theta & \text{for } B \to B' \text{ having } \Delta Y = 0 \ , \\ \sin\theta & \text{for } B \to B' \text{ having } \Delta Y = 1 \ . \end{cases} \qquad (17)$$

There does not really seem to be anything unique about the form (14) for the physical current, it is a phenomenological ansatz like (10). It is, therefore, amazing how the ansatz (14) improves the fit.

IV. COMPARISON WITH EXPERIMENT

The experimental analysis is usally made with the help of the form factors from Eq. (1); for the SG models we therefore express the form factors $f_i^{\alpha'\beta\alpha}$ and $g_i^{\alpha'\beta\alpha}$ in terms of the invariant form factors F_i^γ and G_i^γ (Ref. 10):

$$
\begin{aligned}
f_1^{\alpha'\beta\alpha} &= \sum_{\gamma=1,2} C(\gamma;\alpha'\beta\alpha)\left[F_1^\gamma - \frac{(m_B-m_{B'})^2}{2m_Bm_{B'}}F_2^\gamma + \frac{m_B{}^2-m_{B'}{}^2}{2m_Bm_{B'}}F_3^\gamma\right] ,\\
f_2^{\alpha'\beta\alpha} &= \sum_{\gamma=1,2} C(\gamma;\alpha'\beta\alpha)[(m_B+m_{B'})F_2^\gamma-(m_B-m_{B'})F_3^\gamma]/(2m_Bm_{B'}) ,\\
f_3^{\alpha'\beta\alpha} &+ \sum_{\gamma=1,2} C(\gamma;\alpha'\beta\alpha)[-(m_B-m_{B'})F_2^\gamma+(m_B+m_{B'})F_3^\gamma]/(2m_Bm_{B'}) ,\\
g_1^{\alpha'\beta\alpha} &= \sum_{\gamma=1,2} C(\gamma;\alpha'\beta\alpha)\left[G_1^\gamma + \frac{m_B{}^2-m_{B'}{}^2}{2m_Bm_{B'}}G_2^\gamma - \frac{(m_B-m_{B'})^2}{2m_Bm_{B'}}G_3^\gamma\right] ,\\
g_2^{\alpha'\beta\alpha} &= \sum_{\gamma=1,2} C(\gamma;\alpha'\beta\alpha)[(m_B+m_{B'})G_2^\gamma-(m_B-m_{B'})G_3^\gamma]/(2m_Bm_{B'}) ,\\
g_3^{\alpha'\beta\alpha} &= \sum_{\gamma=1,2} C(\gamma;\alpha'\beta\alpha)[(m_{B'}-m_B)G_2^\gamma+(m_B+m_{B'})G_3^\gamma]/(2m_Bm_{B'}) ,
\end{aligned} \tag{18}
$$

where m_B and $m_{B'}$ are the masses of the initial and final baryon, respectively. In the present section we shall assume that all the form factors are constant; from previous fits using the approximations of Ref. 10 we know that including q^2 dependence will not alter the conclusion. In Sec. V—which was added to the original version—we will present fits in which q^2-dependence of the form factors and radiative corrections are included.

We consider the following types of models: (I) Conventional Cabibbo models based on the equations (1)–(3). (II) Models with the SU(3) group as the spectrum-generating group based on the equations (6)–(8).

The form factors for the vector part of the current are determined from CVC (conserved-vector-current hypothesis). From this one obtains for the two kinds of models:

Models I:

$$
\begin{aligned}
&f_1^\gamma=\sqrt{6} ,\\
&f_1^{\gamma=2}=0 ,\\
&f_2^{\gamma=1}=(\mu_p-1+\mu_n/2)\sqrt{6}/(m_p+m_n) ,\\
&f_2^{\gamma=2}=\mu_n\sqrt{30}/2(m_p+m_n) ;
\end{aligned} \tag{19$_\text{I}$}
$$

Models II:

$$
\begin{aligned}
&F_1^{\gamma=1}=\sqrt{6} ,\\
&F_1^{\gamma=2}=0 ,\\
&F_2^{\gamma=1}=\left[\frac{\mu_p-1}{2}+\frac{\mu_n}{4}\right]\sqrt{6} ,\\
&F_2^{\gamma=2}=\mu_n\sqrt{30}/4 .
\end{aligned} \tag{19$_\text{II}$}
$$

The assumption about the absence of the second-class currents gives for Models I

$$
\begin{aligned}
&f_3^{\gamma=1,2}=0 ,\\
&g_2^{\gamma=1,2}=0 ,
\end{aligned} \tag{20$_\text{I}$}
$$

and for Models II

$$
\begin{aligned}
&F_3^{\gamma=1,2}=0 ,\\
&G_2^{\gamma=1,2}=0 .
\end{aligned} \tag{20$_\text{II}$}
$$

The first-class condition (20$_\text{II}$) for the SG models has been derived from the assumption that the octet current operators have a definite time-inversion transformation property and a definite Hermiticity property[17] and has therefore a fairly well established theoretical foundation. For the conventional Cabibbo model it follows from (20$_\text{I}$) using (2) and (3) that the second-class contributions $f_3^{\alpha'\beta\alpha}$ and $g_2^{\alpha'\beta\alpha}$ are zero for all processes $B(\alpha)\to B'(\alpha')l\nu$.[18] For the SG models it follows from (20$_\text{II}$) using (18) that there are "induced" second-class contributions in the processes $B(\alpha)\to B'(\alpha')l\nu$ and that their magnitude is proportional to the mass difference. This is the most important difference between the conventional Cabibbo model and the SG models and the main reason for the differences in the prediction for the asymmetries and correlation coefficients when large hadron mass differences are involved.

We shall make the fit to the experimental data for the following four models:

Model 1. The Cabibbo model with (10) and $\theta_V\neq\theta_A$.

Model 2. The Cabibbo model with (10) and $\theta_V=\theta_A=\theta_C$.

Model 3. The SG model with Cabibbo current (10) and $\theta_V=\theta_A=\theta_C$.

Model 4. The SG model with the multicommutator current (14).

For models 1 and 2, Eqs. ($19_{\rm I}$) and ($20_{\rm I}$) hold; for models 3 and 4, Eqs. ($19_{\rm II}$) and ($20_{\rm II}$) hold.

By the minimalization of χ^2 we have determined the following parameters for each model:

$$\text{model 1: } \theta_V, \theta_A, g_1^{\gamma=1,2}, g_3^{\gamma=1,2} \;;$$

$$\text{model 2: } \theta_C, g_1^{\gamma=1,2}, g_3^{\gamma=1,2} \;;$$

$$\text{model 3: } \theta_C, G_1^{\gamma=1,2}, G_3^{\gamma=1,2} \;;$$

$$\text{model 4: } A_1, A_2, G_1^{\gamma=1,2}, G_3^{\gamma=1,2} \;.$$

The comparison of the results for these four models is given in Table III. The confidence level of each fit is given in Table IV and the values of the fitted parameters are given in Table V. From Table III we see that, in contrast to the conventional fit[2] of Table I using rates and "experimental" g_A/g_V ratios, the fit of the conventional Cabibbo model to the experimental rates, asymmetries, and correlation coefficients is poor. From the predictions of this model for the α's in Table II one may have expected this. We also see from the comparison of models 1 and 2 in Tables III and V that taking two angles θ_A and θ_V does not improve the situation. It should also be noted that the fit to the two versions of the Cabibbo model is not very sensitive to the values of the form factors $g_3^{\gamma=1,2}$ and setting $g_3^{\gamma=1,2}=0$ would give only a slightly higher value of χ^2. The fit of model 3 is better, as we can see from Table III (improvement from 0.2% confidence level to 1% confidence level), but it is also not a good fit. As far as the rates are concerned it has the same deficiencies as models 1 and 2, the improvement is mainly in the α. As compared to the results of Ref. 10 the fits for models 1, 2 and for model 3 have become worse (the confidence level in both cases has gone down by an order of magnitude); this is mainly due to the change of the experimental values.

Compared to all these fits the fit of model 4 [the SG model with multicommutator current (14)] is remarkable. It improves the agreement for the rates as well as for the α_e's; in particular, $\alpha_e^{\Sigma\to n}$ has the right sign.[3] Its explanation may be a pure accident, but it can be easily tested. An improvement in the value for the rate of $\Xi^- \to \Lambda e\nu$ (Ref. 20) can disprove it easily, as one notices from an inspection of Table III. We remark that if one writes $A_1 = -\delta_1^2/2!$ and $A_2 = \delta_2^4/4!$, then one obtains from the empirical values of Table V $\delta_1 = 0.00752\ (\text{MeV})^{-1}$ and $\delta_2 = 0.00780\ (\text{MeV})^{-1}$, despite the fact that a fit with only one parameter δ is much poorer. This shows the sensitivity of the fit to the precise values of the parameter.

V. THE EFFECT OF RADIATIVE CORRECTIONS, q^2 DEPENDENCE OF THE FORM FACTORS, AND GENUINE SECOND-CLASS TERMS

The effect of radiative corrections and the q^2 dependence of the form factors upon the fit of the Cabibbo model has been discussed in detail in Ref. 19. Soft-photon corrections as well as model-independent hard-photon corrections have been included according to Ref. 20 where it has also been shown that the model-dependent part of the hard-photon corrections are small enough to be neglected at the present level of experimental accuracy. With all corrections taken into account the comparison between model 2 (similar statements hold for the two-angle Cabibbo theory of model 1) and experiment improves slightly; the χ^2 value goes from 33 to 28. This means that the discrepancy between Cabibbo theory and experiment remains significant even after all the corrections have been taken into account. We will here use the same corrections for models 3 and 4.

The radiative corrections affect the theoretical expressions for the rates in the following way:

$$R \to R\left[1+\frac{\alpha}{\pi}\phi\right], \tag{21}$$

where the explicit form and the numerical values for ϕ are computed in Ref. 20 using the approach of Ref. 21. The expressions for the correlation coefficients and the electron and neutrino asymmetries are not affected by ϕ, and for the proton asymmetry cancellations occur so that for all practical purposes

$$\alpha \to \alpha \tag{22}$$

for all α's. Thus radiative corrections are applied only to the rates. Of practical importance are only the Coulomb corrections for the processes with two charged particles in the final state. Therefore only the rates for $n \to pe\nu$ and $\Lambda \to pe\nu$, $\Lambda \to p\mu\nu$ need to be corrected.

The q^2 dependence of the vector form factors have been taken into account in the form

$$F_{1,2}^{BB'}(\hat{q}^2) = C(\gamma=1,B'B)[F_{1,2}^{\gamma=1}(\hat{q}^2=0)+\lambda_{F_{1,2}}^{\gamma=1}\hat{q}^2] + C(\gamma=2,B'B)[F_{1,2}^{\gamma=2}(\hat{q}^2=0)+\lambda_{F_{1,2}}^{\gamma=2}\hat{q}^2]\,, \tag{23}$$

where the four slope parameters $\lambda_{F_{1,2}}^{\gamma}$ have been determined from the slopes of the four electromagnetic form factors of neutron and proton.[22] Thus all eight parameters of the vector current are fixed

TABLE III. The comparison of the results for four models. Experimental data are from Refs. 10 and 26–28. All transition rates are in 10^6 sec^{-1} except for neutron decay, which is in 10^{-3} sec^{-1}.

		Model 1		Model 2		Model 3		Model 4	
Process	Experimental value	Predicted value	Contribution to χ^2	Predicted value	Contribution to χ^2	Predicted value	Contribution to χ^2	Predicted value	Contribution to χ^2
$n \to pe\nu$ (rate)	1.091 ± 0.17	1.045	7.479	1.045	7.443	1.041	8.519	1.086	0.071
$\Sigma^+ \to \Lambda e\nu$ (rate)	0.253 ± 0.059	0.294	0.482	0.295	0.495	0.301	0.655	0.277	0.166
$\Sigma^- \to \Lambda e\nu$ (rate)	0.412 ± 0.034	0.487	4.856	0.488	4.972	0.494	5.848	0.418	0.030
$\Lambda \to pe\nu$ (rate)	3.066 ± 0.109	3.064	0	3.074	0.006	3.066	0	3.086	0.035
$\Sigma^- \to ne\nu$ (rate)	7.287 ± 0.275	7.142	0.279	7.123	0.354	7.098	0.475	7.317	0.012
$\Xi^- \to \Lambda e\nu$ (rate)	1.706 ± 0.731	2.774	2.135	2.730	1.963	2.998	3.126	0.308	3.657
$\Xi^- \to (\Lambda\Sigma^0)e\nu$ (rate)	4.144 ± 1.341	3.297	0.399	3.260	0.435	3.536	0.206	3.217	0.478
$\Lambda \to p\mu\nu$ (rate)	0.597 ± 0.133	0.598	0	0.598	0	0.502	0.512	0.523	0.308
$\Sigma^- \to n\mu\nu$ (rate)	3.036 ± 0.271	3.097	0.051	3.087	0.036	3.175	0.263	2.952	0.097
$n \to pe\nu$ $(\alpha_{e\nu})$	-0.074 ± 0.004	−0.078	1.126	−0.078	1.044	−0.078	1.106	−0.076	0.116
$n \to pe\nu$ (α_e)	-0.084 ± 0.003	−0.086	1.071	−0.086	0.941	−0.086	1.042	−0.083	0.023
$n \to pe\nu$ (α_ν)	1.001 ± 0.038	0.988	0.123	0.988	0.122	0.988	0.123	0.989	0.107
$\Sigma^\pm \to \Lambda e\nu$ $(\alpha_{e\nu})$	-0.400 ± 0.180	−0.400	0	−0.400	0	−0.452	0.082	−0.500	0.306
$\Sigma^- \to ne\nu$ $(\alpha_{e\nu})$	0.280 ± 0.05	0.331	1.029	0.318	0.572	0.308	0.323	0.268	0.058
$\Sigma^- \to ne\nu$ (α_e)	0.040 ± 0.270	−0.696	7.435	0.708	7.679	−0.005	0.027	0.269	0.718
$\Lambda \to pe\nu$ (α_e)	0.125 ± 0.066	0.026	2.252	0.020	2.523	0.008	3.132	−0.004	3.842
$\Lambda \to pe\nu$ $(\alpha_{e\nu})$	0.036 ± 0.037	0.033	0.005	0.022	0.134	0.009	0.519	0.043	0.040
$\Lambda \to pe\nu$ (α_ν)	0.821 ± 0.060	0.973	6.403	0.976	6.644	0.966	5.838	0.901	1.759
$\Lambda \to pe\nu$ (α_p)	-0.508 ± 0.065	−0.582	1.288	−0.580	1.228	−0.565	0.762	−0.512	0.004
Total χ^2			36.413		36.591		32.558		11.863

TABLE IV. Number of degrees of freedom and confidence level of the fit for each model.

	Model 1	Model 2	Model 3	Model 4
Number of degrees of freedom	13	14	14	13
Confidence level	5.1×10^{-4}	8.5×10^{-4}	0.047	0.54

by CVC.

The q^2 dependence of the axial-vector form factors G_1 and G_3 has been taken into account in the same form

$$G_1^{BB'}(\hat{q}^2)=\sum_{\gamma} C(\gamma,B'B)[G_1^{\gamma}(\hat{q}^2=0)+\lambda_{G_1}^{\gamma}\hat{q}^2] \; . \tag{24}$$

The experimental values of the reaction $\nu_\mu+p\rightarrow n+\mu$ were used to obtain the value $M_A=(0.96\pm0.03)$ GeV in the dipole ansatz[22]:

$$g_1^{np}(q^2)=\frac{g_1^{np}(0)}{(1-q^2/M_A{}^2)^2} \approx g_1^{np}(0)\left[1+\frac{2q^2}{M_A{}^2}\right] . \tag{25}$$

Since there is no further information available we assume the same dipole ansatz (25) with the same M_A also for all the other $g_i^{BB'}(q^2)$. The $g_i^{BB'}(q^2=0)$ obeying (25) are then expressed in terms of the $G_i^{\gamma}(\hat{q}^2=0)$. The result is[23]

$$g_1^{BB'}(q^2=0)=\sum_{\gamma} C(\gamma,B'\beta B)\left[G_1^{\gamma}(\hat{q}^2=0)+\frac{m_B{}^2-m_{B'}{}^2}{2m_B m_{B'}}G_3^{\gamma}(\hat{q}^2=0)\right]\left[1+\frac{2(m_B-m_{B'})}{M_A{}^2}\right]^{-1} . \tag{26}$$

$G_2^{\gamma}=0$ has already been assumed in (26) and $G_1^{\gamma}(0), G_3^{\gamma}(0)$ are the four free parameters that are determined in the fit.

Tables VI and VII give the fits of the various models with radiative corrections and q^2-dependent form factors. If we compare these fits with the fits in Table IV we notice that the corrections do not change our conclusion. The corrections give a slight improvement for the fits of the Cabibbo model and for the fit of model 3 and they make the fit of model 4 slightly worse. But the fit of model 2 is still the worst with 1% confidence level (C.L.) and the fit of model 4 is the best with 20% C.L. (Ref. 24). But in view of model 1 (with two angles) one cannot say that the data we use for these fits will rule out the Cabibbo model. However, with the new value of $\alpha_e^{\Sigma n}=+0.35\pm0.25$,[3] (and the new world average $\alpha_e^{\Sigma n}=0.25\pm0.19$) which was published after all these fits were made, one probably has to revise that statement.

To demonstrate that the values given by our fits for the asymmetries are really predictions we have included Tables VIII and IX. They show fits to the correlation coefficients $\alpha_{e\nu}$ and rates Γ, only excluding the polarization asymmetries $\alpha_e,\alpha_p,\alpha_\nu$. Radiative corrections and q^2 dependence of the form factors are included as in Table VI. We see that the fits of all models to rates and $\alpha_{e\nu}$ are very good. Then we calculate the values of the asymmetries from the parameters obtained in the above

TABLE V. Values of the fitted parameters for each model.

Model 1	Model 2	Model 3	Model 4
$\theta_V=0.233$			$A_1=-0.2831\cdot10^{-4}$ MeV^{-2}
	$\theta_C=0.230$	$\theta_C=0.238$	
$\theta_A=0.228$			$A_2=0.1542\cdot10^{-9}$ MeV^{-4}
$g_1^{\gamma=1}=1.051$	$g_1^{\gamma=1}=1.049$	$G_1^{\gamma=1}=0.987$	$G_1^{\gamma=1}=0.717$
$g_1^{\gamma=2}=-1.529$	$g_1^{\gamma=2}=-1.531$	$G_1^{\gamma=2}=-1.578$	$G_1^{\gamma=2}=-1.757$
$g_3^{\gamma=1}=218.4$ GeV^{-1}	$g_3^{\gamma=1}=213.6$ GeV^{-1}	$G_3^{\gamma=1}=-11.29$	$G_3^{\gamma=1}=-13.79$
$g_3^{\gamma=2}=-116.6$ GeV^{-1}	$g_3^{\gamma=2}=-112.7$ GeV^{-1}	$G_3^{\gamma=1}=-40.51$	$G_3^{\gamma=2}=-85.59$

TABLE VI. Fit of different models to the experimental decay rates, correlation coefficients, and asymmetries. In all models radiative corrections and q^2 dependence of form factors have been taken into account. Decay rates are in 10^6 sec^{-1} except for neutron decay which is in 10^{-3} sec^{-1}.

Process	Experimental value	Model 1 Predicted value	Model 1 Contribution to χ^2	Model 2 Predicted value	Model 2 Contribution to χ^2	Model 3 (with two angles) Predicted value	Model 3 (with two angles) Contribution to χ^2	Model 3 (with one angle) Predicted value	Model 3 (with one angle) Contribution to χ^2	Model 4 Predicted value	Model 4 Contribution to χ^2
$n\to pe\nu$ (rate)	1.091 ± 0.017	1.079	0.511	1.079	0.484	1.063	2.620	1.071	1.368	1.119	2.796
$\Sigma^+\to\Lambda e\nu$ (rate)	0.253 ± 0.059	0.277	0.172	0.282	0.243	0.286	0.313	0.303	0.711	0.286	0.322
$\Sigma^-\to\Lambda e\nu$ (rate)	0.412 ± 0.034	0.461	2.055	0.468	2.759	0.468	2.688	0.495	5.970	0.431	0.317
$\Lambda\to pe\nu$ (rate)	3.066 ± 0.109	3.040	0.057	3.113	0.186	3.040	0.058	3.085	0.031	3.081	0.019
$\Sigma^-\to ne\nu$ (rate)	7.287 ± 0.275	7.139	0.290	7.005	1.051	7.052	0.732	7.128	0.333	7.344	0.043
$\Xi^-\to\Lambda e\nu$ (rate)	1.706 ± 0.731	3.033	3.295	2.755	2.060	3.442	5.640	2.983	3.051	0.375	3.318
$\Xi^-\to(\Lambda\Sigma^0)e\nu$ (rate)	4.144 ± 1.341	3.492	0.236	3.257	0.438	3.955	0.020	3.531	0.209	3.208	0.487
$\Lambda\to p\mu\nu$ (rate)	0.597 ± 0.133	0.597	0	0.596	0	0.547	0.144	0.531	0.249	0.555	0.102
$\Sigma^-\to n\mu\nu$ (rate)	3.036 ± 0.271	3.323	1.124	3.241	0.571	3.330	1.180	3.126	0.110	2.880	0.332
$n\to pe\nu$ ($\alpha_{e\nu}$)	-0.074 ± 0.004	−0.076	0.184	−0.075	0.031	−0.077	0.537	−0.076	0.144	−0.073	0.223
$n\to pe\nu$ (α_e)	-0.084 ± 0.003	−0.084	0	−0.082	0.181	−0.085	0.242	−0.083	0.008	−0.079	2.191
$n\to pe\nu$ (α_ν)	1.001 ± 0.038	0.988	0.109	0.989	0.104	0.988	0.115	0.989	0.108	0.990	0.091
$\Sigma^\pm\to\Lambda e\nu$ ($\alpha_{e\nu}$)	$-0.4\ \ \pm0.18$	−0.410	0.003	−0.410	0.003	−0.476	0.180	−0.477	0.185	−0.523	0.471
$\Sigma^-\to ne\nu$ ($\alpha_{e\nu}$)	0.280 ± 0.05	0.337	1.294	0.255	0.259	0.306	0.267	0.296	0.097	0.266	0.078
$\Sigma^-\to ne\nu$ (α_e)	$0.04\ \ \pm0.27$	−0.562	4.979	−0.652	6.561	0.055	0.003	0.272	0.735	0.357	1.374
$\Lambda\to pe\nu$ (α_e)	0.125 ± 0.066	0.034	1.900	−0.001	3.672	0.013	2.869	0.024	2.340	0.011	2.979
$\Lambda\to pe\nu$ ($\alpha_{e\nu}$)	0.036 ± 0.037	0.035	0.001	−0.036	3.766	0.031	0.021	−0.005	1.209	0.027	0.054
$\Lambda\to pe\nu$ (α_ν)	0.821 ± 0.06	0.956	5.043	0.976	6.713	0.905	1.963	0.975	6.553	0.905	1.949
$\Lambda\to pe\nu$ (α_p)	-0.508 ± 0.065	−0.576	1.103	−0.568	0.842	−0.532	0.136	−0.587	1.466	−0.530	0.118
Total χ^2			22.356		29.924		19.728		24.877		17.254

TABLE VII. Values of the fitted parameters for all models considered in Table VI.

Model 1	Model 2	Model 3 (with two angles)	Model 3 (with one angle)	Model 4
$\theta_V=0.235$		$\theta_V=0.273$		$A_1=-0.2755\times10^{-4}$ MeV^{-2}
	$\theta_C=0.223$		$\theta_C=0.246$	
$\theta_A=0.209$		$\theta_A=0.234$		$A_2=0.1426\times10^{-9}$ MeV^{-4}
$g_1^{\gamma=1}=1.088$	$g_1^{\gamma=1}=1.073$	$G_1^{\gamma=1}=0.973$	$G_1^{\gamma=1}=0.923$	$G_1^{\gamma=1}=0.630$
$g_1^{\gamma=2}=-1.470$	$g_1^{\gamma=2}=-1.487$	$G_1^{\gamma=2}=-1.554$	$G_1^{\gamma=2}=-1.605$	$G_1^{\gamma=2}=-1.798$
$g_3^{\gamma=1}=174.6$ GeV^{-1}	$g_3^{\gamma=1}=141.3$ GeV^{-1}	$G_3^{\gamma=1}=-2.35$	$G_3^{\gamma=1}=-27.21$	$G_3^{\gamma=1}=-26.50$
$g_3^{\gamma=2}=-89.7$ GeV^{-1}	$g_3^{\gamma=2}=-63.1$ GeV^{-1}	$G_3^{\gamma=2}=-50.54$	$G_3^{\gamma=2}=-53.13$	$G_3^{\gamma=2}=-99.27$

fits. They are listed in the lower part of the table. We see that the thus predicted values for the asymmetries are essentially the same as the values obtained in the fits to all data of Table VI. This means that the parameters of all models are already completely constrained by the experimental values of the rates and correlation coefficients. We also see that the predictions of the asymmetries are in good agreement for the SG models 3 and 4 and that the agreement is poorer for the Cabibbo model 2. With the new value for $\alpha_e^{\Sigma n}$ the discrepancy between the experimental world average and the prediction of model 2 is more than 4σ.

The characteristic difference between the Cabibbo models 1 and 2 and the SG models 3 and 4 is the occurrence of the induced g_2 term according to the formula (18). The conclusions that we draw from all our fits is therefore that a substantial g_2 term is very important. We would, of course, like to test how essential the particular form of the g_2 term is, which is given by (18) [and which follows from the relation (5)]:

$$g_2^{\alpha'\alpha}=\sum_{\gamma=1,2}-C(\gamma,\alpha'\beta\alpha)\frac{(m_B-m_{B'})}{2m_Bm_{B'}}G_3^{\gamma}\ . \tag{27}$$

We have, therefore, made a fit of the experimental data (including again all corrections) to a model which is identical to the Cabibbo model except that $g_2^{\gamma=1,2}$ is not set equal to zero. Such a model would be a Cabibbo model with genuine second-class currents. Instead of (27) one has for such a model

$$g_2^{\alpha'\alpha}=\sum_{\gamma=1,2}C(\gamma,\alpha'\beta\alpha)g_2^{\gamma=1,2}\ , \tag{28}$$

where g_2 are two new free parameters [or an equation like (28) with $g_2^{\alpha'\alpha}$ replaced by $m_\alpha g_2^{\alpha'\alpha}$ or $(m_\alpha+m_{\alpha'})g_2^{\alpha'\alpha}$].

This is a theoretically very unattractive assumption because the first-class condition follows from very well established theoretical principles,[17] as remarked already above following Eq. (20). Nevertheless we have made the fit and it is given in Tables X and XI. We see that the confidence level for this fit has indeed improved as compared to model 2 (with $\chi^2/n_D=21/12\triangleq5\%$ C.L.) and has become comparable with model 3. However, if one now takes the new experimental value for $\alpha_e^{\Sigma n}$ into account ($\alpha_e=0.35\pm0.25$ or $\alpha_e=0.25\pm0.19$ for the new world average) and compares it with the predictions of model 3 ($\alpha_e^{\Sigma n}\approx+0.3$) and of the model with genuine second-class currents ($\alpha_e^{\Sigma n}\approx-0.6$), then one sees that the genuine second-class terms (28) are definitely disfavored as compared to the induced second-class terms (27). The total χ^2 of the fits with the new world average of $\alpha_e^{\Sigma n}$ is $\chi^2/n_D\approx36/12\triangleq0.03\%$ C.L. for the model with genuine second-class current and $\chi^2/n_D\approx24/14\triangleq5\%$. C.L. for the worst case of the models with the induced second-class current (model 3 with one angle).

The models that we have tested have two different aspects, the first is the meaning of the flavor group [SU(3) in the present case because for charm decay there are no experimental data available yet] and the second is the form of the weak current. In the Cabibbo model SU(3) has the meaning of a symmetry group—otherwise (2) and (3) do not hold—and the mass differences are only taken into account in the phase space. In the SG models the mass differences are used consistently. Model 3 is an SG model and the comparison between the fits of models 2 and 3 essentially test only the question whether the symmetry-group assumption or the SG assumption is better. The fits decide clearly in favor of SG. Both models use the same form for

TABLE VIII. Fit of different models to the experimental decay rates and correlation coefficients. In the lower part of the table the predicted values of asymmetries are given. The quantity in parentheses would give the value of the contribution to the total value of χ^2 if the corresponding quantity had been fitted. The units are the same as in Table VI. The values listed as total χ^2 come only from the contributions for the quantities used in the fit, not from the predicted asymmetries.

		Model 2		Model 3 (with one angle)		Model 4	
Process	Experimental value	Predicted value	Contributed to χ^2	Predicted value	Contribution to χ^2	Predicted value	Contribution to χ^2
$n \to pe\nu$ (rate)	1.091 ± 0.017	1.076	0.779	1.072	1.218	1.104	0.568
$\Sigma^+ \to \Lambda e\nu$ (rate)	0.253 ± 0.059	0.282	0.241	0.304	0.738	0.274	0.122
$\Sigma^- \to \Lambda e\nu$ (rate)	0.412 ± 0.034	0.468	2.738	0.497	6.208	0.412	0
$\Lambda \to pe\nu$ (rate)	3.066 ± 0.109	3.102	0.109	3.097	0.082	3.085	0.031
$\Sigma^- \to \Lambda e\nu$ (rate)	7.287 ± 0.275	7.026	0.898	7.114	0.394	7.332	0.027
$\Xi^- \to \Lambda e\nu$ (rate)	1.706 ± 0.731	2.750	2.040	2.975	3.013	0.343	3.477
$\Xi^- \to (\Lambda\Sigma^0)e\nu$ (rate)	4.144 ± 1.341	3.250	0.444	3.519	0.217	3.149	0.551
$\Lambda \to p\mu\nu$ (rate)	0.597 ± 0.133	0.597	0	0.527	0.276	0.551	0.120
$\Sigma^- \to n\mu\nu$ (rate)	3.036 ± 0.271	3.250	0.623	3.095	0.047	2.913	0.206
$n \to pe\nu$ ($\alpha_{e\nu}$)	-0.074 ± 0.004	-0.074	0.001	-0.076	0.151	-0.070	1.286
$\Sigma^\pm \to \Lambda e\nu$ ($\alpha_{e\nu}$)	$-0.4 \ \pm 0.18$	-0.410	0.003	-0.475	0.176	-0.518	0.427
$\Sigma^- \to ne\nu$ ($\alpha_{e\nu}$)	0.280 ± 0.05	0.252	0.318	0.310	0.360	0.274	0.013
$\Lambda \to pe\nu$ ($\alpha_{e\nu}$)	0.036 ± 0.037	-0.034	3.578	0.009	0.540	0.030	0.022
$n \to pe\nu$ (α_e)	-0.084 ± 0.003	-0.082	predicted (0.420)	-0.083	predicted (0.005)	-0.076	predicted (6.500)
$n \to pe\nu$ (α_ν)	1.001 ± 0.038	0.989	predicted (0.101)	0.989	predicted (0.108)	0.990	predicted (0.079)
$\Sigma^- \to ne\nu$ (α_e)	$0.04 \ \pm 0.27$	-0.654	predicted (6.614)	0.292	predicted (0.871)	0.357	predicted (1.382)
$\Lambda \to pe\nu$ (α_e)	0.125 ± 0.066	0	predicted (3.614)	0.033	predicted (1.925)	0.020	predicted (2.539)
$\Lambda \to pe\nu$ (α_ν)	0.821 ± 0.06	0.976	predicted (6.674)	0.979	predicted (6.967)	0.917	predicted (2.562)
$\Lambda \to pe\nu$ (α_p)	-0.508 ± 0.065	-0.598	predicted (0.851)	-0.596	predicted (1.851)	-0.544	predicted (0.311)
Total χ^2			11.772		13.420		6.850

TABLE IX. Values of the fitted parameters for all models considered in Table VIII.

Model 2	Model 3 (with one angle)	Model 4
		$A_1=-0.2763\times10^{-4}$ MeV^{-2}
$\theta_C=0.223$	$\theta_C=0.245$	
		$A_2=0.1424\times10^{-9}$ MeV^{-4}
$g_1^{\gamma=1}=1.068$	$G_1^{\gamma=1}=0.923$	$G_1^{\gamma=1}=0.662$
$g_1^{\gamma=2}=-1.487$	$G_1^{\gamma=2}=-1.605$	$G_1^{\gamma=2}=-1.754$
$g_3^{\gamma=1}=145.3$ GeV^{-1}	$G_3^{\gamma=1}=-31.29$	$G_3^{\gamma=1}=-27.21$
$g_3^{\gamma=2}=-66.0$ GeV^{-1}	$G_3^{\gamma=2}=-51.60$	$G_3^{\gamma=2}=91.98$

the current in which the suppression factor is given by the Cabibbo angle. Unfortunately in the test of this aspect the form of the current is not totally irrelevant, because the rates have also to be fitted and these depend strongly upon the suppression factor. If the data for the correlation coefficients and asymmetries were better one could make a fit to these quantities only, which would be totally independent of the form of the suppression factors. The present data for the α's alone (as well as the rates alone) do not yet constrain the model.

The form of the current is tested by the comparison of model 3 and model 4, after one has decided already in favor of the SG assumption (a comparison of model 2 and model 4 is difficult because it mixes these two aspects). Although we found that the fits of model 4 were always better than the fits of model 3 (for different kinds of corrections and different selections of a constraining subset of data) we do not think that the difference is significant. It is remarkable that it was at all possible to do without the Cabibbo angle and describe the suppression as a symmetry-breaking effect that comes from the mass differences. There is no theoretical reason for (14) but the fits with it show that the Cabibbo current (10) is not phenomenolog-

TABLE X. Fit of the Cabibbo model to the experimental decay rates, correlation coefficients, and asymmetries. The second-class octet current has been included in the model. The units are the same as in Table VI.

Process	Experimental value	Predicted value	Contribution to χ^2
$n\to pe\nu$ (rate)	1.091 ± 0.017	1.083	0.219
$\Sigma^+\to\Lambda e\nu$ (rate)	0.253 ± 0.059	0.260	0.015
$\Sigma^-\to\Lambda e\nu$ (rate)	0.412 ± 0.034	0.431	0.305
$\Lambda\to pe\nu$ (rate)	3.066 ± 0.109	3.084	0.027
$\Sigma^-\to ne\nu$ (rate)	7.287 ± 0.275	7.051	0.735
$\Xi^-\to\Lambda e\nu$ (rate)	1.706 ± 0.731	2.876	2.562
$\Xi^-\to(\Lambda\Sigma^0)e\nu$ (rate)	4.144 ± 1.341	3.371	0.333
$\Lambda\to p\mu\nu$ (rate)	0.597 ± 0.133	0.597	0
$\Sigma^-\to n\mu\nu$ (rate)	3.036 ± 0.271	3.286	0.854
$n\to pe\nu$ ($\alpha_{e\nu}$)	-0.074 ± 0.004	-0.076	0.138
$n\to pe\nu$ (α_e)	-0.084 ± 0.003	-0.084	0
$n\to pe\nu$ (α_ν)	1.001 ± 0.038	0.988	0.110
$\Sigma^\pm\to\Lambda e\nu$ ($\alpha_{e\nu}$)	$-0.4\ \ \pm0.18$	-0.387	0.005
$\Sigma^-\to ne\nu$ ($\alpha_{e\nu}$)	0.280 ± 0.005	0.278	0.001
$\Sigma^-\to ne\nu$ (α_e)	$0.04\ \pm0.27$	-0.605	5.710
$\Lambda\to pe\nu$ (α_e)	0.125 ± 0.066	0.053	1.198
$\Lambda\to pe\nu$ ($\alpha_{e\nu}$)	0.036 ± 0.037	0.052	0.197
$\Lambda\to pe\nu$ (α_ν)	0.821 ± 0.06	0.976	6.680
$\Lambda\to pe$ (α_p)	-0.508 ± 0.065	-0.603	2.145
Total χ^2			21.236

TABLE XI. Values of the fitted parameters for the model considered in Table X.

$\theta_C = 0.228$
$g_1^{\gamma=1} = 1.131$
$g_1^{\gamma=2} = -1.454$
$g_2^{\gamma=1} = 0.859\ \text{GeV}^{-1}$
$g_2^{\gamma=2} = -0.479\ \text{GeV}^{-1}$
$g_3^{\gamma=1} = 158.3\ \text{GeV}^{-1}$
$g_3^{\gamma=2} = -80.3\ \text{GeV}^{-1}$

ically unique. However the Cabibbo model is theoretically consistent only in the limit of mass degeneracy whereas the SG model is theoretically consistent also for large mass differences. And the comparison between fits of model 2 and model 3 show that the Cabibbo ansatz (10) can probably only be saved in the framework of the SG assumption.

The most important result of this section is that with the new value for $\alpha_e^{\Sigma n}$ a conventional genuine second-class current is essentially ruled out. Tables X and XI shows only a fit of (28) and in the framework of the Cabibbo model, which ignores mass differences, it is not clear whether the right-hand side should hold for $g_2^{\alpha'\alpha}$ or for $m_\alpha g_2^{\alpha'\alpha}$ or $(m_\alpha + m_{\alpha'})g_2^{\alpha'\alpha}$. We have also made fits with these $g_2^{\alpha'\alpha}$ and found that such minor changes in the pseudotensor term do not change the fits significantly. So it is not the existence of a g_2 term, but it is the appearance of the mass differences in the induced g_2 term as given by (27) which is important for an improvement in the predictions of the asymmetries. We had not expected such a result from the present experimental data.

The main result of this paper—especially when combined with the results of fits of the precision values for the hyperon magnetic moments,[25] which also clearly favor the SG assumptions—is that SU(3) predictions are of much higher accuracy than the commonly believed 15–30%. SU(3) can describe precision values but it has to be interpreted in the right way.

Note added in proof. After completion of our work, we were informed of a paper by S. Pakvasa, A. McDonald, and S. P. Rosen [Phys. Rev. 181, 1948 (1969)] in which the possibility of an extension of the axial-vector current has been also considered, and the same method of the derivation of the supression of the $\Delta S = 1$ current has been applied. Large possible deviations from the octet rule for the $\Sigma^- \to ne\nu$ decay have also been indicated.

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