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THE VALUES OF $\Sigma^- \rightarrow ne\nu$ DECAY PARAMETERS AND THE THEORY OF HYPERON SEMILEPTONIC DECAYS†

A. Bohm, A. García,* P. Kielanowski,** M. Kmiecik and R.B. Teese
Center for Particle Theory, University of Texas
Austin, Texas 78712

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ABSTRACT

All solutions of the standard Cabibbo model and the Spectrum Generating Group model are obtained which are allowed by the latest experimental data excluding the value for $\alpha_e^{\Sigma^- \rightarrow ne\nu}$. With the values of the parameters fixed by these experimental data, predictions of the various models for $\alpha_e^{\Sigma^- \rightarrow ne\nu}$ and other yet unmeasured decay parameters are obtained. It is shown that for most of the decay parameters there are only minor differences between the predictions from the various models, except for $\alpha_e^{\Sigma^- \rightarrow ne\nu}$ and $\alpha_\nu^{\Sigma^- \rightarrow ne\nu}$ where the differences are significant.

RESUMEN

Se obtienen todas las soluciones del modelo estándard de Cabibbo y del modelo del Grupo Generador de Espectro que están permitidos por los datos experimentales más recientes, excluyendo el valor $\alpha_e^{\Sigma^- \rightarrow ne\nu}$. Con los valores de los parámetros fijados por estos datos, se obtienen las predicciones de los distintos modelos para $\alpha_e^{\Sigma^- \rightarrow ne\nu}$ y para otros parámetros de de

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* Permanent Address: Departamento de Física, Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional, Apartado Postal 14-740, México 14, Distrito Federal, México.

** On leave from the Institute of Theoretical Physics, University of Warsaw, Warsaw, Poland.

sintegraciones aún no medidas. Se muestra que para la mayoría de los parámetros de desintegración, sólo hay diferencias menores entre las predicciones de los distintos modelos; excepto para $\alpha_e^{\Sigma^-\to ne\nu}$ y $\alpha_\nu^{\Sigma^-\to ne\nu}$, donde las diferencias son significativas.

1. INTRODUCTION

The recent WA2 experiment at CERN[1] produced a large volume of data on the hyperon semileptonic decays. For the first time in a single experiment all important decays were measured and compared with existing theoretical models: Cabibbo model and bag model[1,2], Spectrum Generating Group model[3], Ademollo-Gatto expansion and higher multiplets in the current[4]. The methods used for the comparison in Refs 1-4 differ significantly. In Ref. 1 only the data from the WA2 experiment (rates and g_1/f_1 ratios) are used for the comparison. Ref.2 uses world averaged data for the rates and g_1/f_1 ratios. In Refs.3,4 the comprehensive set of world averaged data is used to compare the rates, correlation coefficients and asymmetries with the predictions of the Cabibbo model. The results of the analysis in Ref. 1 are to some extent contradictory to those of Refs.2-4. The main conclusion of Refs.2-4 is that the symmetry breaking is being observed in semileptonic hyperon decays while Ref. 1 reports very good agreement of the data with the simplest version of the Cabibbo model.

The other outstanding problem of the experimental status of the Cabibbo theory is the sign of the g_1/f_1 ratio for $\Sigma^-\to ne\nu$. The first measurement[5] indicates that the sign should be opposite to the one predicted by the Cabibbo theory while the WA2 paper favors the Cabibbo like sign.

The only model known to us that can well accomodate all the results for semileptonic decays of hyperons (including the non-Cabibbo sign of the g_1/f_1 ratio for $\Sigma^-\to ne\nu$) is the Cabibbo model with SU(3) treated as the spectrum generating group[6]. The experiment in progress at Fermilab should provide us with a value for $\alpha_e^{\Sigma^-\to ne\nu}$ in which we can have confidence.

In view of this experiment it is important:

i) To review the experimental situation and test the various models using the world averaged data including the one from the WA2 experiment.

ii) To find the solutions of the various models to the experimental data excluding the value for $\alpha_e^{\Sigma^- \to ne\nu}$. This will allow us to make all the predictions for α_e that are possible for these models when only the well established data are taken into account. It will also show us the minimal set of data required to fix the parameters of the model.

iii) To predict the values for yet unmeasured decay parameters of the not so well observed processes.

This will show which processes and observables are the most sensitive to differentiate between these models. We will also give predictions for the rates of the not yet observed decays.

The plan of our paper is the following. In Section 2 we briefly review all the considered theoretical models. In Section 3 we describe the observables relevant to the semileptonic hyperon decays and review the present status of the experimental situation. In Section 4 we determine the parameters of the Cabibbo model and of the spectrum generating group model (SG model). Section 5 is devoted to the discussion of the predictions of all the considered models for the new processes and observables. In Section 6 we give the conclusions.

2. THEORETICAL MODELS FOR SEMILEPTONIC HYPERON DECAYS

The current for the transition matrix element is[7]

$$J_\mu = \begin{cases} \cos(\theta_C)\,(V_\mu^{1-i2} + A_\mu^{1-i2}) \text{ for } \Delta S = 0 \\ \\ \sin(\theta_C)\,(V_\mu^{4-i5} + A_\mu^{4-i5}) \text{ for } \Delta S = 1 \end{cases} \quad . \tag{1}$$

The upper indices in the current (1) are the SU(3) indices.

The V-A[8] transition matrix element for the decay $B \to B' l \nu$ is the following:

$$M = \frac{G}{\sqrt{2}} \left\{ \begin{array}{ll} \cos(\theta_C) & \text{for } \Delta S = 0 \\ & \\ \sin(\theta_C) & \text{for } \Delta S = 1 \end{array} \right\} \bar{u}_{B'}(f_1^{B'B}\gamma^\mu + f_2^{B'B} i\sigma^{\mu\nu}q_\nu + f_3^{B'B}q^\mu$$

$$+ g_1^{B'B}\gamma^\mu\gamma_5 + g_2^{B'B} i\sigma^{\mu\nu}q_\nu\gamma_5 + g_3^{B'B}q^\mu\gamma_5)u_B \times \bar{v}_\nu\gamma_\mu(1-\gamma_5)u_1 . \tag{2}$$

The f_1, f_2 and f_3 are vector current form factors and g_1, g_2 and g_3 are axial vector current form factors.

From Eq.(1) it follows that the form factors f_i and g_i are equal:

$$\begin{aligned} f_i^{B'B} &= \sum_{\gamma=F,D} C(\gamma;\alpha'\beta\alpha) f_i^{(\gamma)} \quad , \\ g_i^{B'B} &= \sum_{\gamma=F,D} C(\gamma;\alpha'\beta\alpha) g_i^{(\gamma)} \quad . \end{aligned} \tag{3}$$

In Eq.(3) the $C(\gamma;\alpha'\beta\alpha)$ are the Clebsch-Gordan coefficients of the SU(3) group and α, α' and β are SU(3) quantum numbers of B, B´ and the current and $f_i^{(\gamma)}$ and $g_i^{(\gamma)}$ are the SU(3) reduced form factors, γ stands for F (antisymmetric) or D(symmetric). The vector part of the current in Eq.(1) is in the same octet as the electromagnetic current[8] (CVC), and thus the vector current SU(3) form factors can be determined from the hyperon magnetic moments.

The derivation of Eq.(3) is based on the Wigner-Eckart theorem which requires that the hadron momentum P_μ commutes with the generators E_α of the SU(3) group:

$$[P_\mu, E_\alpha] = 0 \quad . \tag{4}$$

Eq.(4) is certainly not fulfilled exactly since the masses in the hyperon octet are not all equal. The Cabibbo theory can therefore be only approximate with an accuracy that depends upon the degree of violation of Eq.(4).

An alternative to Eq.(4) is the assumption that the hadron 4-velocity $\hat{P}_\mu = P_\mu M^{-1}$ commutes with the generators of the SU(3) group[(9)]:

$$[\hat{P}_\mu, E_\alpha] = 0 \quad . \tag{4´}$$

Eq. (4´) is not in immediate contradiction with the variation of masses within the multiplet so we shall treat this equation as exact.

Eq. (4´) requires that the formulas (1) and (3) be slightly reformulated: the momentum transfer q_μ has to be replaced by the velocity transfer

$$\hat{q} = \frac{P_B}{M_B} - \frac{P_{B'}}{M_{B'}} \tag{5}$$

After this replacement the formulas (2) and (3) read

$$M = \frac{G}{\sqrt{2}} \left\{ \begin{array}{ll} \cos(\theta_C) & \text{for } \Delta S=0 \\ \\ \sin(\theta_C) & \text{for } \Delta S=0 \end{array} \right\} \bar{u}_{B'} (F_1^{B'B}\gamma^\mu + F_2^{B'B} i\,\sigma^{\mu\nu}\hat{q}_\nu + F_3^{B'B}\hat{q}^\mu$$

$$+G_1^{B'B}\gamma^\mu\gamma_5 + G_2^{B'B} i\sigma^{\mu\nu}\hat{q}_\nu\gamma_5 + G_3^{B'B}\hat{q}^\mu\gamma_5) u_B \times \bar{v}_\nu\, \gamma_\mu (1-\gamma_5) u_1 \quad ; \tag{2'}$$

$$\begin{aligned} F_i^{B'B} &= \sum_{\gamma=F,D} C(\gamma;\alpha'\beta\alpha) F_i^{(\gamma)} \; ; \\ G_i^{B'B} &= \sum_{\gamma=F,G} C(\gamma;\alpha'\beta\alpha) G_i^{(\gamma)} \; . \end{aligned} \tag{3´}$$

All the form factors in Eqs.(2´) and (3´) are functions of the velocity transfer[(5)]. This difference is reflected by denoting them by capital letters. Both sets of form factors can be expressed by one another. The relevant formulas are given in Ref.10.

When both versions of the Cabibbo model are confronted with the latest, very accurate experimental data, there are significant deviations present. Therefore, further refinements are necessary. They include radiative corrections, q^2 dependence of the form factors and perhaps also some admixture of the currents transforming according to the 10, $\overline{10}$ and 27 representations of the SU(3) group.

The radiative corrections are important only for the rates. They can be divided into two parts: the model independent part and the model dependent part. The model dependent part can be included by rescaling the weak coupling constant:

$$G \rightarrow G\times(1+C) \quad . \tag{6}$$

Our evaluation of C is C = 1%.

The model independent part depends upon the process considered and is largest for the neutral hyperon decays where it is dominated by the Coulomb term. Explicit values of the model independent part of the radiative corrections are given in Ref.11.

The q^2 dependence is important for the f_1 and g_1 form factors only. We assume that their functional dependence on q^2 is the following*:

$$\begin{aligned} f_1(q^2) &= f_1(0)\times(1 + \frac{2q^2}{M_V^2}) \quad , \\ g_1(q^2) &= g_1(0)\times(1 + \frac{2q^2}{M_A^2}) \quad , \end{aligned} \tag{7}$$

with M_V=0.84 GeV/c², M_A=1.08 GeV/c² for ΔS=0 and M_V=0.97 GeV/c², M_A=1.25 GeV/c² for ΔS=1[1].

The current given in Eq.(1) can be generalized to contain also other representations of the SU(3) group. Only the currents transforming according to the 10, $\overline{10}$ and 17 representations of SU(3) can give non van-

* The results are not very sensitive to the particular values of M_V and M_A, but the experimental data are sufficiently accurate that they are sensitive to the presence of the q^2 dependence of the form factors. Omitting them makes the agreement of theory with experiment significantly worse.

ishing contribution for semileptonic decays. The other outstanding problem is the contruction of the current. We will assume that the current is obtained by the rotation of the $\Delta S=0$ current through the angle θ_C around the 7th axis in the SU(3) space[4,12]:

$$J_\mu = e^{-2i\theta_C F_7} J_\mu(\Delta S=0) e^{2i\theta_C F_7} \quad , \tag{8}$$

where

$$J_\mu(\Delta S=0) = J_\mu^{(8,1-i2)} + J_\mu^{(10,1-i2)} + J_\mu^{(\overline{10},1-i2)} + J_\mu^{(27,1-i2)} \quad . \tag{9}$$

This form leads to the lengthy formula for the current which is given in Ref.4. An alternative approach to the construction of the current is given in Ref.12. To calculate the matrix element of the current (8) one needs the appropriate Clebsch-Gordan coefficients. The full set of the Clebsch-Gordan coefficients is given in Table I.

3. PRESENT EXPERIMENTAL SITUATION

The experimental situation in hyperon decays has greatly improved in the last three years. For the first time high statistics experiments have been performed and the results published[1,13]. In Ref.1, as mentioned before, all important electron modes of the semileptonic hyperon decays have been measured. The results given in Ref.1 are the following:

$$\Sigma^- \to \Lambda e \nu \quad \text{Br. ratio} = (0.561 \pm 0.031) \times 10^{-4}, \quad \frac{f_1}{g_1} = 0.03 \pm 0.08$$

$$\Sigma^- \to n e \nu \quad \text{Br. ratio} = (0.96 \pm 0.05) \times 10^{-3} \quad , \quad \frac{g_1}{f_1} = -0.34 \pm 0.05$$

$$\Xi^- \to \Lambda e \nu \quad \text{Br. ratio} = (0.564 \pm 0.031) \times 10^{-3}, \quad \frac{g_1}{f_1} = 0.25 \pm 0.05$$

TABLE I

process	8_F	8_D	10	$\overline{10}$	27_{I_1}	27_{I_2}
$n \to p$	$\frac{1}{\sqrt{6}}$	$-\frac{\sqrt{3}}{\sqrt{10}}$	$-\frac{\sqrt{2}}{\sqrt{15}}$	$\frac{\sqrt{2}}{\sqrt{15}}$	$\frac{2\sqrt{2}}{3\sqrt{15}}$	0
$\Sigma^{\pm} \to \Lambda$	0	$-\frac{1}{\sqrt{5}}$	$\frac{1}{\sqrt{5}}$	$\frac{1}{\sqrt{5}}$	$-\frac{2}{3\sqrt{5}}$	0
$\Lambda \to p$	$-\frac{1}{2}$	$\frac{1}{2\sqrt{5}}$	0	$-\frac{1}{\sqrt{5}}$	$\frac{\sqrt{2}}{\sqrt{15}}$	0
$\Sigma^- \to n$	$-\frac{1}{\sqrt{6}}$	$-\frac{\sqrt{3}}{\sqrt{10}}$	$\frac{\sqrt{2}}{\sqrt{15}}$	$\frac{\sqrt{2}}{\sqrt{15}}$	$-\frac{2}{9\sqrt{5}}$	$-\frac{2}{9}$
$\Xi^- \to \Lambda$	$\frac{1}{2}$	$\frac{1}{2\sqrt{5}}$	0	$\frac{1}{\sqrt{5}}$	$-\frac{\sqrt{2}}{\sqrt{15}}$	0
$\Xi^- \to \Sigma^0$	$\frac{1}{2\sqrt{3}}$	$-\frac{\sqrt{3}}{2\sqrt{5}}$	$\frac{2}{\sqrt{15}}$	$-\frac{1}{\sqrt{15}}$	$-\frac{2}{9\sqrt{10}}$	$\frac{2\sqrt{2}}{9}$
$\Sigma^0 \to p$	$-\frac{1}{2\sqrt{3}}$	$-\frac{\sqrt{3}}{2\sqrt{5}}$	$-\frac{2}{\sqrt{15}}$	$\frac{1}{\sqrt{15}}$	$-\frac{2}{9\sqrt{10}}$	$\frac{2\sqrt{2}}{9}$
$\Xi^0 \to \Sigma^+$	$\frac{1}{\sqrt{6}}$	$-\frac{\sqrt{3}}{\sqrt{10}}$	$-\frac{\sqrt{2}}{\sqrt{15}}$	$-\frac{\sqrt{2}}{\sqrt{15}}$	$-\frac{2}{9\sqrt{5}}$	$-\frac{2}{9}$
$\Xi^- \to \Xi^0$	$\frac{1}{\sqrt{6}}$	$\frac{\sqrt{3}}{\sqrt{10}}$	$-\frac{\sqrt{2}}{\sqrt{15}}$	$\frac{\sqrt{2}}{\sqrt{15}}$	$-\frac{2\sqrt{2}}{3\sqrt{15}}$	0
$\Sigma^- \to \Sigma^0$	$\frac{1}{\sqrt{3}}$	0	$\frac{1}{\sqrt{15}}$	$-\frac{1}{\sqrt{15}}$	0	$\frac{2}{3\sqrt{3}}$
$\Sigma^0 \to \Sigma^+$	$-\frac{1}{\sqrt{3}}$	0	$-\frac{1}{\sqrt{15}}$	$\frac{1}{\sqrt{15}}$	0	$\frac{2}{3\sqrt{3}}$
$\Xi^- \to n$	0	0	0	$\frac{\sqrt{2}}{\sqrt{5}}$	0	$-\frac{2}{3\sqrt{3}}$
$\Xi^0 \to p$	0	0	0	$\frac{\sqrt{2}}{\sqrt{5}}$	0	$\frac{2}{3\sqrt{3}}$
$\Sigma^+ \to n$	0	0	0	$\frac{\sqrt{2}}{\sqrt{5}}$	0	$\frac{2}{3\sqrt{3}}$
$\Xi^0 \to \Sigma^-$	0	0	0	$-\frac{\sqrt{2}}{\sqrt{5}}$	0	$\frac{2}{3\sqrt{3}}$

Table I. Complete table of the Clebsch-Gordan coefficients for the 16 hyperon semileptonic decays. $I_1=1$, $I_2=2$ for $\Delta S=0$ and $I_1=\frac{1}{2}$, $I_2=\frac{3}{2}$ for $\Delta S=1$.

$$\Xi^- \to \Sigma^\circ e\nu \qquad \text{Br. ratio}=(0.87\pm0.17)\ 10^{-4}$$

(10)

$$\Lambda^- \to pe\nu \qquad \text{Br. ratio}=(0.857\pm0.036)\times10^{-3}, \qquad \frac{g_1}{f_1} = 0.70\pm0.03$$

In Ref.13, only the process $\Lambda \to pe\nu$ has been considered. The published results are preliminary since only a fraction of all the data has been analyzed (10,039 events). Nevertheless, it is the $\Lambda \to pe\nu$ experiment with the highest statistics. The results published in Ref.13 are the following:

$$R = \frac{\Gamma(\Lambda \to pe\nu)}{\Gamma(\Lambda \to p\pi^-)} = (1.313\pm0.024)\times10^{-3}$$

or

$$\Gamma(\Lambda \to pe\nu) = (3.204\pm0.068)\times10^{6}\ \text{sec}^{-1} \tag{11}$$

and

$$\frac{g_1}{f_1} = 0.715\pm0.025 \quad .$$

The value of g_1/f_1 obtained in the analysis of the experimental data depends on the value of g_2 through the relation

$$\frac{g_1}{f_1} = 0.715 + 0.25\times\frac{g_2}{f_1} \quad , \tag{12}$$

and the data indicate that g_2 should be small.

The results in Refs. 1,13 are consistent with each other, and they are also consistent with the earlier data[14], so it is admissible to average these results. Moreover the value of g_1/f_1 depends very weakly on q^{2}(13). This averaging yields

$$\Gamma(\Lambda\to pe\nu) = (3.187\pm0.057)\times10^{6}\sec^{-1} \quad ,$$

$$\frac{g_1}{f_1} = 0.690\pm0.034 \quad . \tag{13}$$

Branching ratio and g_1/f_1 are the most common observables for semileptonic hyperon decays. Determination of g_1/f_1 requires very detailed knowledge of other form factors. The usual assumptions are: f_1 and f_2 are determined from the CVC and g =0. Because of that, these experimental values of g_1/f_1 cannot be used for the comparison of the theories that do not fulfill these assumptions, and, *e.g.*, the prediction for g_1/f_1 of the model with $g_2\neq0$ cannot be compared with the experimental g_1/f_1. To avoid such problems, we use also other observables. They are the electron-neutrino correlation coefficient and electron, neutrino and final baryon asymmetries. They are defined by

$$\alpha = 2\times\frac{N_+-N_-}{N_++N_-} \quad , \tag{14}$$

where $N_{+(-)}$ is the number of events with cos $\theta_{e\nu}>(<)0$ for $\alpha_{e\nu}$, cos $\theta_e>(<)0$ for α_e, cos $\theta_\nu>(<)0$ for α_ν and cos $\theta_{B'}>(<)0$ for $\alpha_{B'}$. The initial baryon has to be polarized for the measurement of α_e, α_ν and $\alpha_{B'}$, and the angles of particle momenta are measured with respect to the direction of the polarization of the initial baryon.

If the polarization of the final baryon can be measured, then there are additional observables. They are related to the asymmetries of the decay products of the final baryon. We call these observables A and B. Their definition is given in Ref.16, and they are also briefly discussed in Ref.1.

The full set of the experimental data used for the determination of the parameters of the models is given in Table II. The data in the Table II are essentially the data of Ref.15 which are updated and aug-

TABLE II

process	experimental value
$n \to p\ e\nu$ (rate)	1.114±0.020
$\Sigma^+ \to \Lambda\ e\nu$ (rate)	0.250±0.063
$\Sigma^- \to \Lambda\ e\nu$ (rate)	0.387±0.018
$\Lambda \to p\ e\nu$ (rate)	3.180±0.058
$\Sigma^- \to n\ e\nu$ (rate)	6.896±0.235
$\Xi^- \to \Lambda\ e\nu$ (rate)	3.352±0.367
$\Xi^- \to \Sigma^o e\nu$ (rate)	0.53 ±0.104
$\Lambda \to p\ \mu\nu$ (rate)	0.596±0.133
$\Sigma^- \to n\ \mu\nu$ (rate)	3.036±0.271
$\Xi^- \to \Lambda\ \mu\nu$ (rate)	2.133±2.133
$n \to p\ e\nu$ ($\alpha_{e\nu}$)	-0.074±0.004
$n \to p\ e\nu$ (α_e)	-0.083±0.002
$n \to p\ e\nu$ (α_ν)	0.998±0.025
$\Sigma^\pm \to \Lambda\ e\nu$ ($\alpha_{e\nu}$)	-0.35 ±0.15
$\Sigma^- \to \Lambda\ e\nu$ ($\alpha_{e\nu}$)	-0.404±0.044
$\Sigma^- \to \Lambda\ e\nu$ (A)	0.07 ±0.07
$\Sigma^- \to \Lambda\ e\nu$ (B)	0.85 ±0.07
$\Lambda \to p\ e\nu$ ($\alpha_{e\nu}$)	-0.013±0.014
$\Lambda \to p\ e\nu$ (α_e)	0.125±0.066
$\Lambda \to p\ e\nu$ (α_ν)	0.821±0.060
$\Lambda \to p\ e\nu$ (α_{B^-})	-0.508±0.065
$\Sigma^- \to n\ e\nu$ ($\alpha_{e\nu}$)	0.279±0.026
$\Sigma^- \to n\ e\nu$ (α_e)	0.26 ±0.19
$\Xi^- \to \Lambda\ e\nu$ ($\alpha_{e\nu}$)	0.53 ±0.10
$\Xi^- \to \Lambda\ e\nu$ (A)	0.62 ±0.10

Table II. Experimental data for semileptonic hyperon decays. Rates are in $10^6 sec^{-1}$ with the exception of the rate for $n \to pe\nu$ which is in $10^{-3}\ sec^{-1}$.

mented by the recent experiments[1,5,13]. The references to the earlier experiments are in Ref. 15.

4. DETERMINATION OF THE PARAMETERS OF THE MODELS

Let us first consider the standard Cabibbo model. The parameters of this model are θ_C, $g_1^{(F)}$ and $g_1^{(D)}$. As mentioned before, the vector current SU(3) reduced form factors f_i^{γ} are determined through CVC from the charges and the hyperon magnetic moments. $g_2^{(\gamma)}$ are assumed to vanish from the assumption of the absence of the second class currents, and $g_3^{(\gamma)}$ can be neglected because they enter in the experimentally measured quantities with the factor m_1/m_B Thus there are effectively three parameters to be fitted.

In the case of the SG model we have 5 parameters: θ_C, $G_1^{(F)}$, $G_1^{(D)}$, $G_3^{(F)}$ and $G_3^{(D)}$. As in the case of the standar Cabibbo model the vector current form factors are determined through CVC and $G_2^{(F)} = G_2^{(D)} = 0$ from the assumption of the absence of the second class currents. $G_3^{(F)}$ and $G_3^{(D)}$ now enter the $g_1^{B'B}$ and $g_2^{B'B}$ through a symmetry breaking term proportional to $m_B-m_{B'}$, so that there are now 5 effective parameters.

The parameters of all the models can be determined either from the full set of the data or from a suitable subset. In our determination we shall not use the full set of data. First we exclude experimental g_1/f_1's. We could have used these data for the determination of the parameters of the standar Cabibbo model. Our aim, however, is to compare the predictions of the standard Cabibbo model with the SG model. The g_1/f_1's cannot be used for the SG model, because it predicts $g_2^{B'B} \neq 0$. So in order to have a consistent picture we have to use the same set of data for the determination of the parameters of all the models, and this excludes the use of g_1/f_1's.

Not all the data in Table II are equally well described by the Cabibbo model. The strongest contradiction between the theory and experiment is for $\alpha_e(\Sigma^-\to ne\nu)$. In order to be free of that contradiction, to avoid any possible bias and to see which value the various models predict for it, we have decided to exclude this experimental result from the set of the data from which we determined the parameters.

To determine the parameters of all the models we have performed the χ^2 fits of the free parameters to all the models.

In the Table III we have given the values of the parameters of all the models together with the corresponding value of χ^2. It is clear that the quality of all the fits is comparable and rather poor.

In the case of the Cabibbo model the solution is unique (case A). In the case of the SG model we have two distinct solutions. The first one (case B) is a small modification of the standard Cabibbo model solution. Its existence is a consequence of the fact that the standard Cabibbo model and the Sg model become identical in the limit of equal masses within the multiplet.

The second solution (case C) for the SG model is significantly different from the first solution. Its characteristic feature is a large value for the parameters $G_3^{(F)}$ and $G_3^{(D)}$. These two solutions give different predictions for the quantities not used in the fit. The most important differences occur for the parameters of the decay $\Sigma^-\to ne\nu$.

The predictions of all the models for the experimentally measured numbers are given in Table IV. The second solution for the SG model (case C) reproduces the experimental value of $\alpha_e(\Sigma^-\to ne\nu)$ very well in contrast to the standard Cabibbo model (case A) and the Cabibbo like solution of the SG model (case B).

With $\alpha_e^{\Sigma^-\to ne\nu}$ excluded the main contribution to χ^2 for all three solutions comes from $\Gamma(\Sigma^-\to\Lambda e\nu)$. Without this one value the fit would be very good. As has been shown before[(2-4)] this discrepancy for $\Gamma(\Sigma^-\to\Lambda e\nu)$ may be a manifestation fo symmetry breaking and can be very well explained by the inclusion of higher representations in the axial current. Including three new parameters for the higher representations in the g_1-form factors one obtains the fits given in Table III (cases D, E and F corresponding to the cases A,B and C, respectively). In all three cases we can note a significant improvement in the quality of the fits. The contribution of the 10 and 27 representations of the SU(3) group are roughly equal and approximately 10% of the octet contribution while the contribution $\overline{10}$ is small.

TABLE III

Parameter	A	B	C	D	E	F
$\sin(\theta_C)$	0.225±0.002	0.239±0.003	0.244±0.002	0.224±0.003	0.241±0.008	0.252±0.007
$g_1^{(F)}$ or $G_1^{(F)}$	1.10 ±0.01	1.08 ±0.01	1.02 ±0.02	1.12 ±0.02	1.11 ±0.02	1.06 ±0.04
$g_1^{(D)}$ or $G_1^{(D)}$	-1.46 ±0.01	-1.48 ±0.01	-1.52 ±0.01	-1.37 ±0.03	-1.39 ±0.04	-1.46 ±0.03
$G_3^{(F)}$	-	-2.2 ±3.1	-16.6 ±3.7	-	1.0 ±4.7	-9.8 ±8.1
$G_3^{(D)}$	-	3.2 ±4.3	-41.2 ±3.8	-	2.6 ±8.5	-40.1 ±5.5
g_1^{10} or G_1^{10}	-	-	-	-0.13 ±0.03	-0.13 ±0.03	-0.11 ±0.03
$g_1^{\overline{10}}$ or $G_1^{\overline{10}}$	-	-	-	0.06 ±0.03	0.05 ±0.04	0.0 ±0.04
g_1^{27} or G_1^{27}	-	-	-	-0.09 ±0.03	-0.11 ±0.04	-0.09 ±0.05
χ^2	40.51	42.93	44.17	13.88	14.67	19.45

Table III. Values of the fitted parameters for different models. A - standard Cabibbo model, B - SG model - first solution, C - SG model - second solution. Cases D, E and F are like A, B and C but higher representations in the current are also included.

TABLE IV

process	A	B	C	D	E	F
$n \to p\, e\nu$ (rate)	1.095	1.087	1.083	1.104	1.096	1.090
$\Sigma^+ \to \Lambda\, e\nu$ (rate)	0.276	0.276	0.281	0.234	0.235	0.237
$\Sigma^- \to \Lambda\, e\nu$ (rate)	0.458	0.457	0.461	0.389	0.388	0.389
$\Lambda \to p\, e\nu$ (rate)	3,209	3.238	3.231	3.161	3.176	3.177
$\Sigma^- \to n\, e\nu$ (rate)	6.757	6.566	6.592	7.984	6.873	6.784
$\Xi^- \to \Lambda\, e\nu$ (rate)	2.878	2.717	2.979	2.233	3.161	3.376
$\Xi^- \to \Sigma^o\, e\nu$ (rate)	0.512	0.549	0.551	0.541	0.624	0.677
$\Lambda \to p\, \mu\nu$ (rate)	0.546	0.550	0.555	0.538	0.541	0.553
$\Sigma^- \to n\, \mu\nu$ (rate)	3.153	3.008	2.984	3.255	3.144	3.133
$\Xi^- \to \Lambda\, \mu\nu$ (rate)	0.820	0.773	0.810	0.918	0.897	0.921
$n \to p\, e\nu$ ($\alpha_{e\nu}$)	-0.074	-0.074	-0.074	-0.076	-0.076	-0.076
$n \to p\, e\nu$ (α_e)	-0.082	-0.081	-0.081	-0.083	-0.083	-0.084
$n \to p\, e\nu$ (α_ν)	0.989	0.989	0.989	0.989	0.989	0.989
$\Sigma^\pm \to \Lambda\, e\nu$ ($\alpha_{e\nu}$)	-0.408	-0.403	-0.463	-0.408	-0.404	-0.466
$\Sigma^- \to \Lambda\, e\nu$ ($\alpha_{e\nu}$)	-0.412	-0.407	-0.473	-0.412	-0.408	-0.476
$\Sigma^- \to \Lambda\, e\nu$ (A)	0.057	0.042	0.044	0.062	0.046	0.048
$\Sigma^- \to \Lambda\, e\nu$ (B)	0.884	0.884	0.901	0.884	0.884	0.901
$\Lambda \to p\, e\nu$ ($\alpha_{e\nu}$)	-0.019	-0.025	-0.027	-0.016	-0.014	-0.014
$\Lambda \to p\, e\nu$ (α_e)	0.009	0.007	0.004	0.011	0.014	0.007
$\Lambda \to p\, e\nu$ (α_ν)	0.977	0.984	0.976	0.976	0.979	0.958
$\Lambda \to p\, e\nu$ ($\alpha_{B'}$)	-0.578	-0.582	-0.574	-0.578	-0.583	-0.563
$\Sigma^- \to n\, e\nu$ ($\alpha_{e\nu}$)	0.334	0.301	0.297	0.294	0.279	0.276
$\Sigma^- \to n\, e\nu$ (α_e)	-0.617	-0.678	0.129	-0.658	-0.702	0.045
$\Xi^- \to \Lambda\, e\nu$ ($\alpha_{e\nu}$)	0.653	0.663	0.723	0.513	0.511	0.642
$\Xi^- \to \Lambda\, e\nu$ (A)	0.455	0.446	0.622	0.632	0.633	0.687

Table IV. Predictions of different models for the observables from Table II. Columns A, B, C, D, E and F have the same meaning as in the Table III.

In Table IV we give the predictions of all the models for the experimentally measured quantities. The most significant remaining deviations are for $\Lambda \to pe\nu$. These deviations can be explained by the right-handed currents[17]. So far this is only a 3 standard deviation effect, but if it is confirmed by future experiments it is an indication that the leptonic current cannot be pure V-A[18].

5. NEW PREDICTIONS

The progress in experimental techniques makes the more accurate measurement of the hyperon decays possible. The predictions of the existing models are a guide for choosing the processes that will provide the most significant information. The measurement of these new processes and observables will serve as a further test of the existing models, will allow us to better distinguish between them and give valuable information on the type of the corrections to the Cabibbo model.

First we shall give predictions for the rates of the not yet measured hyperon semileptonic decays. The results are given in the Table V. From this table one can see that the largest rates are for the decays $\Sigma^0 \to pe\nu$ and $\Sigma^0 \to p\mu\nu$. Experimentally these decays are not possible to observe due to the large Σ^0 width for the electromagnetic decay $\Sigma^0 \to \Lambda\gamma$.

Next come $\Xi^0 \to \Sigma^+ e\nu$ and $\Xi^0 \to \Sigma^+ \mu\nu$ decays. The existing bound for both these decays[14] is not far from the prediction of the Table V for the electron mode. The measurement of this decay is thus feasible and we give in Table VI the predictions for other decay parameters for the process $\Xi^0 \to \Sigma^+ e\nu$.

The next three decays in the Table V are the $\Delta S=0$ decays within the same isomultiplet. The rates for these decays are about 10^6 times smaller than the rates for other semileptonic decay modes for these particles. They thus seem to be inaccessible experimentally.

The remaining 8 decays from Table V are either $\Delta S=2$ or $\Delta I=\frac{3}{2}$ processes, so they are forbidden in the standard Cabibbo model and in the SG model with octet currents. They are also forbidden in the Cabibbo model with the symmetry breaking scheme of Ref.19. On the other hand if

TABLE V

Process	exp upper bound	A	B	C	D	E	F
$\Sigma^o \to p\ e\nu$	-	3.155	3.081	3.075	2.839	2.819	3.011
$\Sigma^o \to p\ \mu\nu$	-	1.438	1.378	1.366	1.297	1.262	1.320
$\Xi^o \to \Sigma^+ e\nu$	3.8	0.901	0.968	0.973	0.745	0.841	0.954
$\Xi^o \to \Sigma^+ \mu\nu$	3.8	0.776E-2	0.834E-2	0.868E-2	0.642E-2	0.725E-2	0.856E-2
$\Xi^- \to \Xi^o e\nu$	-	0.154E-5	0.158E-5	0.170E-5	0.127E-5	0.129E-5	0.143E-5
$\Sigma^- \to \Sigma^o e\nu$	-	0.903E-6	0.881E-6	0.843E-6	0.867E-6	0.855E-6	0.835E-6
$\Sigma^o \to \Sigma^+ e\nu$	-	0.866E-7	0.845E-7	0.808E-7	0.831E-7	0.820E-7	0.801E-7
$\Xi^- \to n\ e\nu$	19.5	0.000	0.000	0.000	0.183E-2	0.797E-3	0.016
$\Xi^- \to n\ \mu\nu$	91.4	0.000	0.000	0.000	0.130E-2	0.565E-3	0.012
$\Xi^o \to p\ e\nu$	4.5	0.000	0.000	0.000	0.062	0.059	0.015
$\Xi^o \to p\ \mu\nu$	4.5	0.000	0.000	0.000	0.044	0.041	0.011
$\Sigma^+ \to n\ e\nu$	0.06	0.000	0.000	0.000	0.441E-2	0.198E-2	0.037
$\Sigma^+ \to n\ \mu\nu$	0.4	0.000	0.000	0.000	0.190E-2	0.855E-3	0.016
$\Xi^o \to \Sigma^- e\nu$	3.1	0.000	0.000	0.000	0.430E-2	0.471E-2	0.109E-2
$\Xi^o \to \Sigma^- \mu\nu$	3.1	0.000	0.000	0.000	0.832E-5	0.909E-5	0.211E-5

Table V. Predictions for the rates of the not yet observed hyperon semileptonic decays. The rates are in the units of 10^6sec-1. Columns A, B, C, D, E and F have the same meaning as in the Table III.

TABLE VI

$\Xi^o \to \Sigma^+ e\nu$

observable	A	B	C	D	E	F
$\alpha_{e\nu}$	-0.216	-0.216	-0.262	-0.170	-0.180	-0.250
α_e	-0.206	-0.199	-0.215	-0.162	-0.160	-0.199
α_ν	0.980	0.979	0.983	0.989	0.989	0.988
$\alpha_{B'}$	-0.438	-0.454	-0.455	-0.469	-0.481	-0.456
A	0.652	0.632	0.632	0.698	0.672	0.651
B	0.669	0.687	0.693	0.627	0.653	0.677
g_1/f_1	1.250	1.291	1.195	1.116	1.168	1.125

Table VI. Observables for $\Xi^o \to \Sigma^+ e\nu$. Columns A, B, C, D, E and F have the same meaning as in the Table III.

in the axial current there are terms tranforming according to the 10, $\overline{10}$ or 27 representations of the SU(3) group then these processes become allowed and their observation would be a strong evidence for the presence of higher representations in the weak current. The predictions of the model with higher representations in the axial current are given in columns D,E and F of the Table V.

For two decays $\Xi^0\to pe\nu$ and $\Sigma^+\to ne\nu$ the existing experimental upper bound for the rate is not very far from our predictions. These decays are therefore very good candidates for the search of higher representations in the axial current. Very interesting phenomenon can also be noticed for the other observables for these decays. The only non vanishing form factor for these decays is g_1. For this reason the electron-neutrino correlation coefficient $\alpha_{e\nu}$ and the asymmetries α_e, α_ν and $\alpha_{B'}$ do not depend on the particular value of g_1, but are determined by the phase space only. The predictions for these observables are the following:

$\Xi^0\to pe\nu$	$\Sigma^+\to ne\nu$
$\alpha_{e\nu} = -0.7452$	$\alpha_{e\nu} = -0.6057$
$\alpha_e = -0.7171$	$\alpha_e = -0.6990$
$\alpha_\nu = 0.7171$	$\alpha_\nu = 0.6990$
$\alpha_{B'} = 0$	$\alpha_{B'} = 0$

The deviation from this prediction would be the evidence for the existence of the second class current (through the form factor g_2) or presence of higher representations in the vector current. In either case the deviation should be small (proportional to $(m_B-m_{B'})/(m_B+m_{B'})$). The disappointing element of this prediction is that these data cannot help us to distinguish between the models.

The important question is how to distinguish experimentally between the various models. The predictions of the Cabibbo model (cases A and D) and the first solutions of the SG model (cases B and E) are very close to one another. To be able to distinguish between these cases one would need very high statistics experiments for precise measurements of the form factors (*e.g.*, the measurement of g_2/f_1). This possibility seems to be rather remote, so presently these two cases are indistinguishable.

The second solution for the SG model is characterized by large values of $G_3^{(\gamma)}$, which implies large values of the g_3 form factors for some processes. As mentioned before the contribution of the form factor g_3 is suppressed by the factor m_1/m_B so these large values of g_3 do not have an appreciable influence on the observables. The importance of large $G_3^{(\gamma)}$'s is based on its influence on the values of the g_1 and g_2 form factors. The contribution of $G_3^{(F)}$ and $G_3^{(D)}$ to the g_1 and g_2 form factors is suppressed by the factor $(m_B-m_{B'})/\sqrt{m_B m_{B'}}$ so large $G_3^{(\gamma)}$'s can manifest themselves best when the mass difference is large. This is the case for $\Sigma^-\to ne\nu$ where, due to the $G_3^{(\gamma)}$'s, the sign of g_1 form factor has been changed thus reproducing the experimental value of α_e. The predictions for all the observables for $\Sigma^-\to ne\nu$ are given in Table VII. One can see the dramatic difference in all the asymmetries between the cases C,F and A,B, D,E. The absolute value of g_1/f_1 by itself does not allow to distinguish between the two models. The information of Ref.1 about the sign of g_1/f_1 for $\Sigma^-\to ne\nu$ favors the negative sign over the positive sign by 2.6 standard deviations so there appeared to be a strong contradiction with the value of g_1/f_1 obtained from α_e. In Ref.20 it has been shown that such a contradiction can arise because g_2 was set equal to zero in the analysis of the data of Ref.1, and that all the experimental data for $\Sigma^-\to ne\nu$ are in fact consistent provided the g_2 form factor is large.

The other processes which show a systematic difference between the standard Cabibbo model and the SG model are the decays $\Sigma^+\to\Lambda e\nu$ and $\Sigma^-\to\Lambda e\nu$. The predictions for these processes are given in the Table VIII. The most significant difference occurs for $\alpha_{e\nu}$ for both processes. The $\alpha_{e\nu}$ is larger for the second solution of the SG model by 10% more than for the standard Cabibbo model. Smaller differences are also present for the other observables. It is important to note than $\alpha_{e\nu}$ can be rather precisely measured since no polarized hyperons are needed for its determination. The direct precise measurement of $\alpha_{e\nu}$ for $\Sigma^\pm\to\Lambda e\nu$ can thus discriminate between the two models.

Table VII

$\Sigma^- \to ne\nu$

observable	A	B	C	D	E	F
$\alpha_{e\nu}$	0.334	0.301	0.297	0.294	0.279	0.276
α_e	-0.617	-0.678	0.129	-0.658	-0.702	0.045
α_ν	-0.389	-0.393	0.189	-0.382	-0.388	0.132
$\alpha_{B'}$	0.693	0.735	-0.175	0.716	0.749	-0.082
g_1/f_1	-0.348	-0.402	0.458	-0.376	-0.423	0.366

Table VII. Observables for $\Sigma^- \to ne\nu$. Columns A, B, C, D, E and F have the same meaning as in the Table III.

Table VIII

$\Sigma^+ \to \Lambda e\nu$

observable	A	B	C	D	E	F
$\alpha_{e\nu}$	-0.408	-0.403	-0.463	-0.408	-0.404	-0.466
α_e	-0.703	-0.699	-0.713	-0.705	-0.701	-0.716
α_ν	0.643	0.647	0.659	0.641	0.644	0.658
$\alpha_{B'}$	0.077	0.065	0.066	0.083	0.071	0.071
A	0.052	0.039	0.039	0.056	0.042	0.043
B	0.885	0.885	0.889	0.885	0.855	0.899
f_1/g_1	0.000	-0.004	-0.004	0.000	-0.004	-0.004

$\Sigma^- \to \Lambda e\nu$

observable	A	B	C	D	E	F
$\alpha_{e\nu}$	-0.412	-0.407	-0.473	-0.412	-0.408	-0.476
α_e	-0.707	-0.702	-0.719	-0.709	-0.705	-0.723
α_ν	0.642	0.644	0.660	0.639	0.642	0.658
$\alpha_{B'}$	0.085	0.072	0.073	0.092	0.078	0.080
A	0.057	0.042	0.044	0.062	0.046	0.048
B	0.884	0.884	0.901	0.884	0.884	0.901
f_1/g_1	0.000	-0.004	-0.005	0.000	-0.005	-0.005

Table VIII. Observables for $\Sigma^+ \to \Lambda e\nu$ and $\Sigma^- \to \Lambda e\nu$. Columns A, B, C, D, E and F have the same meaning as in the Table III.

The next important question is the presence of higher representations in the axial vector current. It can be detected in two ways. The first one is the observation of the processes forbidden in the standard Cabibbo model and allowed by the current with higher representations included. The processes that can serve for this purpose are: $\Xi^- \to n e \nu$, $\Xi^o \to p e \nu$, $\Sigma^+ \to n e \nu$, $\Xi^o \to \Sigma^- e \nu$ and the muon modes for these processes. As mentioned before out of these processes the experimental upper bound is the closest for $\Sigma^+ \to n e \nu$, $\Sigma^+ \to n \mu \nu$ and $\Xi^o \to p e \nu$, $\Xi^o \to p \mu \nu$. Any experimental confirmation of the higher representations should be made by searching for these processes. The existing data for the well measured semileptonic hyperon decays are not sufficient to uniquely determine the existence of higher representations in the weak current since the existing deviations can be explained by other means of symmetry breaking.

6. CONCLUSIONS

The semileptonic hyperon decays is still the most important area for the verification of the structure of the weak currents. The present data are not fully compatible with the standard Cabibbo model. The main discrepancies are:

1. Rate for $\Sigma^- \to \Lambda e \nu$ coming from one experiment(1).
2. α_e for $\Sigma^- \to n e \nu$ coming from four consistent experiments, one of which is statistically significant.
3. α_e, α_ν and α_B, for $\Lambda \to p e \nu$ coming from several consistent experiments(21).

The first discrepancy (~3.6σ) can be explained either by Ademollo-Gatto symmetry breaking or by the presence of the higher representations in the weak current. The observation of the forbidden processes would be evidence for the higher representations in the current. If the experimental upper limits for the rates of these processes are reduced below our predictions then the only remaining possibility is the symmetry breaking. In either case the corrections to the existing theoretical models are of the order of 10%.

The second discrepancy cannot be corrected within the standard Cabibbo model by small corrections. If the existing value of α_e for

$\Sigma^- \to ne\nu$ is confirmed by the current experiment at Fermilab then it will be very difficult to reconcile this value with the standard Cabibbo models. This value of α_e is in very good agreement with the SG model and it may serve as evidence for this type of the models. The other quantity that may be able to distinguish between these two models is the value $\alpha_{e\nu}$ for $\Sigma^{\pm} \to \Lambda e\nu$.

The third discrepancy cannot be explained by either of these models. The existing values for these observables should be checked experimentally. If they are confirmed, it may serve as evidence for right handed currents, and then the other processes should be checked for the presence of such currents also. It should also be stressed that from the rate and g_1/f_1 alone, one cannot detect the right handed currents.

The answers to all these problems can only be given by high statistics experiments with polarized initial hyperons.

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