On the new value for the electron asymmetry in $\Sigma^- \to ne\nu$ and hyperon semileptonic decays

A. Bohm and M. Kmiecik
Center for Particle Theory, The University of Texas at Austin, Austin, Texas 78712
(Received 5 November 1984)

Using the new value for $\alpha_e^{\Sigma^- \to n}$, fits of the hyperon-decay data are presented. They show that there is excellent agreement between the predictions of the Cabibbo model and the experimental data, except for perhaps two indications of minor corrections.

The experimental value of the electron asymmetry in $\Sigma^- \to ne\nu$ was of considerable concern because the world average (consistent with four old experiments) of $\alpha_e^{\Sigma^- \to n} = 0.26 \pm 0.19$ was in contradiction with the prediction of the standard theory. The only explanation of this value—which was consistent with all other experimental data—was that the pseudotensor form factor for this process, $g_2^{\Sigma^- \to n}$, was huge and caused by a large value of the SU(3)-invariant g_3 form factor.[1] The new value obtained for this asymmetry[2] by the Fermilab experiment 715 of $\alpha_e^{\Sigma^- \to n} = -0.58 \pm 0.16$ shows that this concern was unjustified.

To demonstrate how well the standard theory agrees now with a large number of experimental data, but also to expose the few minor deviations, we present here a fit of the Cabibbo model to the hyperon-semileptonic-decay data. In our fits we have used exact expressions for the rate R and for $R\alpha$ in terms of the form factors f_1, f_2, f_3, g_1, g_2, and g_3 in which the phase-space factors are obtained by numerical integration.[3] We have also included radiative corrections[4] and q^2 dependence of the leading form factors in a linear approximation with the slope determined from the slope of the electromagnetic form factors and from neutrino scattering.[5]

We report here two different kinds of fits. In fit I of the ordinary Cabibbo model, the form factors $f_i^{B'B}$ and $g_i^{B'B}$ $(i = 1,2,3)$ for each individual process $B \to B'l\nu$ are expressed in terms of multiplet form factors F_i^F, F_i^D, G_i^F, and G_i^D by formulas like

$$g_i^{B'B} = C^F(B'B)G_i^F + C^D(B'B)G_i^D \ , \tag{1}$$

where the C^F and C^D are the F- and D-type Clebsch-Gordan coefficients. With $F_1^{F,D}$ and $F_2^{F,D}$ determined from CVC (conserved vector current) and with $F_3^{F,D}$, $G_2^{F,D}$, and $G_3^{F,D}$ equal to zero,[6] it has three free parameters [$\sin\theta_C$, $(1/\sqrt{6})G_1^F = F$, $-\sqrt{3/10}G_1^D = D$] to be determined from 25 experimental data. In fit II the form factors $f_i^{B'B}$ and $g_i^{B'B}$ are expressed in terms of multiplet form factors by formulas like[7]

$$g_1^{B'B} = \sum_{\gamma=F,D} C^\gamma(B'B)\left(G_1^\gamma + \frac{m_B{}^2 - m_{B'}{}^2}{2m_B m_{B'}} G_2^\gamma + \frac{(m_B - m_{B'})^2}{2m_B m_{B'}} G_3^\gamma \right) \ . \tag{2}$$

F_1 and F_2 are again determined by CVC and the G_2 are zero (second class). Thus one has five free parameters ($\sin\theta_C$, G_1^F, G_1^D, G_3^F, G_3^D) to be determined from the 25 data. For this spectrum-generating (SG) model the mass differences between the hyperons have been taken into account. In the limit of zero mass differences the two models are identical. But, as one can see from the form (2) and the corresponding expressions for the other form factors,[7] these two models become virtually indistinguishable if $G_3^{F,D}$ is for some reason close to zero.

In Table I we present the comparison between 25 experimental values (given in the second column of the table) and the prediction of the Cabibbo model (given in the third column) without any symmetry breaking. The contribution that each of the fitted predictions makes to χ^2 is listed in the fourth column, and we see that the 15% discrepancy[8] for $R(\Sigma \to \Lambda e\nu)$ is the only significant (4σ) deviation. This can be easily explained by a small perturbative correction in the form of the 8 component of an octet in the strong-interaction Hamiltonian[9] or by a small $\mathbf{10}$-$\overline{\mathbf{10}}$ contribution in the weak current[10] and should not cause any worries. Of greater concern are the small deviations for the asymmetries in $\Lambda \to pe\nu$ which contribute about 10 to χ^2. These deviations cannot be explained by symmetry breaking, second-class currents, or violation of CVC. If they are confirmed by future experiments, they will be a sign that the leptonic current cannot be pure $V-A$. They can, e.g., be explained by a right-handed current.[11]

The fifth column of Table I gives the predictions for the model that takes the hyperon mass differences into account and in which the form factors are given by formulas like (2). Here one has two more parameters, but the experimental data determine them to be consistent with zero (see Table II). If one fixes $G_3^F = G_3^D = 0$, one obtains essentially the same predictions with the same χ^2 as those in the fifth column. It is only $\alpha_e^{\Sigma^- \to n}$ that determines the parameters of fit II uniquely. If one does not use $\alpha_e^{\Sigma^- \to n}$, one obtains a second solution[1] with large values for $G_3^{F,D}$, which is now clearly ruled out by the new value for $\alpha_e^{\Sigma^- \to n}$.

A χ^2 of about 40 for about 20 degrees of freedom may not look so good. But if one takes into consideration that the main contribution comes from one experimental value $R(\Sigma^- \to \Lambda e\nu)$, which can be easily explained by a 10% correction term that will bring the χ^2 down to about 15, then one can only marvel at the agreement. As this 10% symmetry-breaking effect shows only in one experimental value, one may wonder whether it is there at all. Excluding

TABLE I. Comparison between the experimental hyperon-semileptonic-decay data and the predictions of the Cabibbo model. Only those data in the second column for which we give a contribution to χ^2 in the fourth and sixth columns have been used in the fit for the determination of the parameters. The g_1/f_1 ratios in the third and fifth columns have been calculated from the parameters in Table II. We also list the predictions for the other asymmetries in $\Sigma^- \to ne\nu$.

		Experimental value	Fit I Predicted values, standard model	Fit I Contribution to χ^2	Fit II Predicted values, model with mass corrections	Fit II
$n \to pe\nu$	R	1.114 ± 0.020	1.095	0.9	1.085	1.9
	$\alpha_{e\nu}$	-0.074 ± 0.004	-0.074	0.0	-0.074	0.0
	α_e	-0.083 ± 0.002	-0.082	0.5	-0.081	0.8
	α_ν	0.998 ± 0.025	0.989	0.1	0.989	0.1
	α_p		-0.48		-0.48	
	g_1/f_1	1.254 ± 0.006	1.249		1.249	
$\Sigma^+ \to \Lambda e\nu$	R	0.250 ± 0.063	0.276	0.2	0.276	0.2
	$\alpha_{e\nu}$	-0.35 ± 0.15	-0.41	0.1	-0.40	0.1
	f_1/g_1	-0.37 ± 0.22	± 0.00		-0.004	
$\Sigma^- \to \Lambda e\nu$	R	0.387 ± 0.018	0.458	15.7	0.456	14.9
	$\alpha_{e\nu}$	-0.404 ± 0.044	-0.412	0.0	-0.408	0.0
	A	0.07 ± 0.07	0.06	0.0	0.04	0.2
	B	0.85 ± 0.07	0.88	0.2	0.88	0.2
	f_1/g_1	-0.14 ± 0.24	± 0.000		-0.004	
$\Lambda \to pe\nu$	R	3.180 ± 0.058	3.207	0.2	3.239	1.0
	$\alpha_{e\nu}$	-0.013 ± 0.014	-0.019	0.2	-0.025	0.8
	α_e	0.125 ± 0.066	0.009	3.1	0.007	3.2
	α_ν	0.821 ± 0.060	0.977	6.7	0.984	7.4
	α_n	-0.508 ± 0.065	-0.578	1.1	-0.582	1.3
	f_1/g_1	0.719 ± 0.023	0.717		0.759	
$\Sigma^- \to ne\nu$	R	6.896 ± 0.235	6.768	0.3	6.550	2.1
	$\alpha_{e\nu}$	0.279 ± 0.026	0.333	4.2	0.296	0.4
	α_e	-0.58 ± 0.16	-0.618	0.0	-0.671	0.3
	α_ν		-0.389		-0.386	
	α_n		0.694		0.726	
	g_1/f_1		-0.349		-0.391	
$\Xi^- \to \Lambda e\nu$	R	3.352 ± 0.367	2.876	1.6	2.723	2.9
	$\alpha_{e\nu}$	0.53 ± 0.10	0.654	1.5	0.664	1.7
	A	0.62 ± 0.1	0.455	2.7	0.448	2.9
	g_1/f_1	0.248 ± 0.05	0.184		0.182	
$\Xi^- \to \Sigma^0 e\nu$	R	0.53 ± 0.10	0.51	0.0	0.55	0.0
	g_1/f_1		1.25		1.29	
$\Lambda \to p\mu\nu$	R	0.596 ± 0.133	0.549	1.4	0.550	0.1
$\Sigma^- \to n\mu\nu$	R	3.036 ± 0.271	3.158	2.0	3.008	0.0
$\Xi^- \to \Lambda\mu\nu$	R	2.133 ± 2.133	0.819	0.4	0.775	0.4
χ^2				39		41

TABLE II. Values of the parameters. The values for $G_3^{F,D}$ are consistent with zero. In a fit in which they are fixed at zero, the predictions in the fifth column of Table I remain the same (except for minor changes in the third decimal). However, $G_3^{F,D}$ could also be of order one.

	Fit I	Fit II
$\sin\theta$	0.225 ± 0.002	0.239 ± 0.003
$(1/\sqrt{6})G_1^F = F$	0.450 ± 0.006	0.440 ± 0.006
$-\sqrt{3/10}G_1^D = D$	0.799 ± 0.007	0.809 ± 0.007
$(1/\sqrt{6})G_3^F$		-0.92 ± 1.28
$-\sqrt{3/10}G_3^D$		-1.38 ± 2.32

$R(\Sigma^- \to \Lambda e\nu)$ from the fit, the χ^2 for both fit I and II goes down to about 20.

Summarizing, we have seen that the new value for $\alpha_e^{\Sigma \to n}$ leads to marvelous agreement between the experimental numbers for hyperon semileptonic decays and the predictions of the Cabibbo model, and that the SG model with its additional degrees of freedom is completely superfluous. The three parameters of the Cabibbo model are already determined by the $n \to pe\nu$ data and by the rate and $\alpha_{e\nu}$ for $\Lambda \to pe\nu$. So $\alpha_e^{\Sigma \to n} \approx -0.6$ and all the other values in the third column of Table I are already predictions of the model, a remarkable achievement indeed.

This work was supported in part by the U.S. Department of Energy under Grant No. ER0339.

[1]A. Bohm, P. Kielanowski, and A. Garcia, Phys. Rev. D **30**, 231 (1984).
[2]Elmhurst College, Fermilab, University of Iowa, Iowa State University, Leningrad Nuclear Physics Institute, University of Chicago report presented at Annual Meeting of the Division of Particles and Filelds of the APS, Santa Fe, 1984 (unpublished).
[3]A. Garcia and P. Kielanowski, *The Beta Decay of Hyperons,* Springer Lecture Notes in Physics (Springer, Berlin, 1984).
[4]A. Garcia, Phys. Rev. D **25**, 1348 (1982); W. Marciano and A. Sirlin, Phys. Rev. Lett. **46**, 163 (1980).
[5]A. Bohm and P. Kielanowski, Phys. Rev. D **27**, 166 (1983).
[6]There is no reason for $G_3^{F,D}$ to be zero in the Cabibbo model. But they enter the experimental quantities with a factor of m_e and their existence does not change the fit.
[7]The detailed expressions are given in Eqs. (18) of Ref. 5.
[8]M. Bourquin *et al.* (WA2 collaboration), Z. Phys. C **12**, 307 (1982).
[9]A. Garcia and P. Kielanowski, Phys. Rev. D **26**, 1090 (1982).
[10]A. Bohm, P. Magnollay, A. Garcia, and P. Kielanowski, Phys. Rev. D **27**, 180 (1983); S. Pakvasa, A. McDonald, and S. P. Rosen, Phys. Rev. **181**, 1948 (1969).
[11]T. Oka, Phys. Rev. Lett. **50**, 1423 (1983).