THE STATUS OF SEMILEPTONIC HYPERON DECAYS
J. Donoghue

To cite this version:

HAL Id: jpa-00221898
https://hal.archives-ouvertes.fr/jpa-00221898
Submitted on 1 Jan 1982

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers. L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
THE STATUS OF SEMILEPTONIC HYPERON DECAYS

J. F. Donoghue

Department of Physics and Astronomy, University of Massachusetts, Amherst, Massachusetts 01003, U.S.A.

Semileptonic hyperon decay has been a traditional area for the study of weak currents. Early work exposed the V-A structure of the currents. Now that we feel that we understand the currents, semileptonic decays may be used for other purposes, such as the study of the KM mixing angles or of the hadronic structure of baryons. In this brief report, I will touch on some of the theoretical and experimental issues of this subject.

The weak Hamiltonian for semileptonic decays may be written as

\[ \mathcal{H}_W = \frac{G_F}{\sqrt{2}} \left( a_1 \mathcal{A} = 0 + b_1 \mathcal{A} = 1 \right) \bar{\psi}_f \gamma^\mu (1 + \gamma_5) \psi_i, \]

where \( \mathcal{A} = 0, 1 \) are the hadronic weak currents. In the Cabibbo-GIM model \( a = \cos \theta_C, \quad b = \sin \theta_C \) with \( \theta_C \) being the Cabibbo angle. In the KM-six quark version \( a = \cos \theta_1, \quad b = \sin \theta_1 \cos \theta_3 \), such that \( a^2 + b^2 \leq 1 \). The matrix elements of the hadronic currents have the general form

\[ \langle B^+ | J_\mu | B^0 \rangle = \bar{u}(p_2) \left( f_1(q^2) \gamma^\mu \gamma_5 \right) \frac{f_2(q^2)}{m_1 + m_2} + f_3(q^2) \frac{g_2(q^2)}{m_1 + m_2} \]

with \( q^2 = (p_1 - p_2)^2 \). T invariance implies that all the form factors are real.

The standard treatment of these form factors invokes CVC, PCAC and SU(3). In the case of \( f_1 \) (the vector form factor) and \( f_2 \) (weak magnetism), we can predict the value of the form factor at \( q^2 = 0 \) from knowledge of electromagnetic transitions by use of CVC plus SU(3). The axial form factor \( g_1 \) may be parameterized by SU(3) in terms of two reduced matrix elements, \( F \) and \( D \). For \( f_3 \) (the scalar form factor) and \( g_2 \) (weak electricity or the second class axial form factor), the standard treatment sets them equal to zero by use of G-parity (for \( \mathcal{A} = 0 \)) plus SU(3) invariance (for \( \mathcal{A} = 1 \)). These two are called "second class". Finally, \( g_3 \) (the pseudoscalar form factor) is known in terms of \( g_1 \) via PCAC. Note that \( f_3 \) and \( g_3 \) are unimportant in decays involving electrons, as their effect is proportional to \( m_e \).

It is always instructive to understand quantities by direct calculations, even if somewhat crude, rather than group-theoretic parameterization. This is now possible for the form factors using the quark model. (Many groups have worked on these form factors using a variety of quark models. Because of space limitations, I will only quote results in my favored model, the MIT bag model.) The weak currents are written in terms of quark fields, and specific matrix elements can single out the different form factors. For states at rest, the time component of the vector current isolates \( f_1 \), with results that reproduce CVC in the SU(3) limit.\(^2\) Likewise a magnetic-moment-like matrix element\(^3\) can be used to calculate \( f_2 \), again reproducing CVC. For the axial vector form factor\(^2\)
where $u(R)$ is the upper (lower) component in the quarks Dirac wavefunction. The spin factor $<r^+|\bar{c}_3\gamma^5|c>$ is familiar from nonrelativistic SU(6) calculations. The integral will in general lower $g_1$ from 5/3, with results of size $g_1 = 1.09 \pm 1.3$ obtainable in the MIT bag model. The SU(3) transformation property of $g_1$ in quark models is given by $D/D+F = 3/5$, close to the experimental value of 0.65.

The second class form factors, $g_2$ and $f_3$, must vanish in the SU(3) limit, but SU(3) is broken by quark mass differences. These have recently been calculated in the bag model\textsuperscript{13} and a sizeable result was found for $A_S=1$ transitions, these deviations from SU(3) are small (\textsuperscript{6} 3% in the bag model\textsuperscript{2}). However, for the other form factors symmetry breaking corrections can be, and are expected to be, significantly larger.\textsuperscript{2,3}

There are two strong reasons for caring about SU(3) breaking. 1) It affects experimental results. For example, the SU(3) values of $f_1$, $f_2$ and $g_2$ are generally assumed to be true in measurements of the value of $g_1/f_1$, and this assumption ends up being hidden when the final result is used. The results do depend on this assumption. The UMASS–BNL study of $\Lambda \to p\nu\bar{\nu}$ has looked at this and finds a strong correlation\textsuperscript{6} between $g_1/f_1$ and $g_2$. If SU(3) is not valid, neither are the measurements unless all significant correlations are quoted. Alternatively experimenters can use the model independent parameterization provided in a recent preprint by A. Garcia and P. Kielanowski. 2) SU(3) breaking may affect the theoretical analysis. For example, the bounds on the KM angles are fairly sensitive to SU(3) breaking.\textsuperscript{7}

The experimental situation is improving rapidly with results from new high statistics experiments. The WA2 collaboration, running at the CERN SPS, has accumulated thousands of events in each of five transitions. Their preliminary results were presented at the Lisbon Conference last year\textsuperscript{8} (however, beware of errors in the discussion) and the final results are slowly coming out.\textsuperscript{9} The UMASS–BNL group has published\textsuperscript{5,10} results based on 10,000 $\Lambda \to p\nu\bar{\nu}$ events and are analyzing the 100,000 events that they have on tape (which contain polarization information also). When this is done, many aspects of this reaction will be known better than has been possible even for neutron $\beta$ decay.

One interesting conflict with standard theory is the electron asymmetry in $\Sigma^- \to n\nu\bar{\nu}$ reported recently by the Argonne-Chicago-Ohio State collaboration.\textsuperscript{11} They have a low statistics experiment (193 events) but have good polarization information. They measure $\alpha_n = 0.35 \pm 0.29$ whereas the usual Cabibbo fit would require $\alpha_n = -0.69$. This parameter is determined dominantly by $g_1/f_1$. The measured value is consistent with the magnitude of $g_1/f_1$ (which is measured precisely elsewhere), but would require the opposite sign. Such a result is very difficult to accommodate in the standard theory. The WA2 group is now quoting a new result on this subject.\textsuperscript{12} They measure the magnitude $|g_1/f_1| = 0.34 \pm 0.05$ and have tried to extract the sign from the electron's energy distribution. This method is very sensitive to radiative corrections, but with their estimated systematic uncertainty in these corrections they favor the negative sign (i.e. the sign predicted by the Cabibbo fit) by 1.60. We need to wait to see their discussion of the corrections, due out shortly, in order to assess this method. There will be an FNAL experiment which should also report on the electron asymmetry.
The other new interesting result is that there is clear evidence for SU(3) breaking (i.e., a failure of the standard Cabibbo type fit) in the data as it now stands (even excluding the electron asymmetry in $\Sigma \to \text{nev}$). This is not that surprising as it simply means that the data is, for the first time, better than the assumption of SU(3) invariance. The compiled data and the fits have been published several places. In general $G_p$ is taken from muon decay, and $\cos \theta_1$ can be extracted from $\pi^+ - \pi^0$ Fermi nuclear $B$ decay ($\cos \theta_1 = 0.9737 \pm 0.0025$). Radiative corrections are now very important. A typical fit now has $\sin \theta_1 \cos \theta_3 = 0.225 \pm 0.002$ (note: $\cos^2 \theta_1 + \sin^2 \theta_1 \cos^2 \theta_3 = 0.999 \pm 0.005$) with a $\chi^2 = 31$ for 11 degrees of freedom. The dynamical cause of this poor fit is not yet clear, but putting in SU(3) breaking expected in the quark model does not help. The breaking has been parameterized in terms of the SU(3) structure of $\xi_1$ or by use of higher representations of SU(3). The pattern of breaking presents us with an opportunity to learn more about the dynamics of the quark model.

References

12. GAILLARD J. M., private communication.