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HYPERON BETA-DECAY*

(Addendum)

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ABSTRACT

To make a previous analysis of hyperon beta-decay complete, the q^2 -spectrum of the decay rate and asymmetry functions are discussed. It is shown that these spectra provide a valuable source of information on the hard to measure form factors f_2 and g_2 .

Hyperon beta-decay was studied in the C.M. Frame of the outgoing leptons in a previous paper¹ (hereafter referred to as I). It was shown that the process

$$A \rightarrow B + \bar{\nu} + \ell \quad (1)$$

with polarized initial particle A can be specified by the variables q^2 (square of 4-momentum transfer from A to B), ψ (angle between the polarization vector $\underline{n}$ of A and 3-momentum $\underline{p}'$ of B in the A rest frame) and θ, ϕ (the polar angles of ℓ with respect to the coordinate axes formed by $\underline{p}', \underline{n}$ and $\underline{p}' \times \underline{n}$ in the C.M. frame of the $(\bar{\nu} \ell)$ system). In terms of these variables the differential decay distribution is given, in the usual current-current interaction theory, by

$$\begin{aligned} \frac{d^4\Gamma}{dq^2 d(\cos \psi) d(\cos \theta) d\phi} &= (G^2 M_-^3 / 27 \pi^4) (M_+ / 2M_A)^3 [(1 - q^2/M_+^2)(1 - q^2/M_-^2)]^{\frac{1}{2}} \times \\ &\{ [I_1 \sin^2 \theta + I_2 \frac{1}{2}(1 + \cos^2 \theta) + I_3 \cos \theta] \\ &+ p \cos \psi [I_4 \sin^2 \theta + I_5 \frac{1}{2}(1 + \cos^2 \theta) + I_6 \cos \theta] \quad (2) \\ &+ p \sin \psi \sin \theta [I_7 \cos \phi + I_8 \sin \phi] \\ &+ p \sin \psi \sin \theta \cos \theta [I_9 \cos \phi + I_{10} \sin \phi] \end{aligned}$$

where $M_{\pm} = M_A \pm M_B$ and p is the polarization of the particle A.

The coefficients $\{I_i\}$, are quadratic functions of the baryon form factors and depend only on the variable q^2 . We showed in I how the angular dependences of (2) can be utilized to determine all the coefficients $\{I_i\}$ from experimental data by measuring various asymmetries.

Since the expression (2) contains the full amount of information which is, in principle, available from reaction (1), we complete the analyses of I in this note by discussing the q^2 -dependences of the coefficient functions $\{I_i\}$ and their relation to measurements. We will show that the q^2 -spectrum of the total rate and/or some of the asymmetry functions discussed previously can yield valuable information on the theoretically interesting form factors f_2 and g_2 .

For simplicity and practicality, we shall confine ourselves to the case where the lepton mass is negligible and set equal to zero. Generalization to the (lepton) mass non-zero case can be made in a straightforward manner from formulas given in I. As is pointed out in I, for almost all hyperon beta-decays, it is practical to: (i) expand the measurable quantities in the small parameter $\delta = (M_-/M_+)$ keeping only terms to order δ and (ii) assume the invariant form factors f_1 , f_2 , g_1 and g_2 to be independent of their argument q^2 . This is because the error incurred by these approximations is expected to be smaller than both the anticipated experimental error and the as yet uncalculated radiative corrections. Since q^2 is confined to the range $0 < q^2 < M_-^2$, it is also convenient to use the variable

$$z = q^2/M_-^2 \quad (3)$$

which has the range $0 < z < 1$. From straight forward calculations one obtains the z -spectrum for the decay rate as well as for the coefficient functions $\{I_i\}$ (which correspond to various measured asymmetries as explained in I),

$$\begin{aligned}
 \frac{dR}{dz} &= [G^2 M_-^5 / 24 \pi^3 (1+\delta)^3] [1-z]^{\frac{1}{2}} \\
 &\times \{ [|f_1|^2 + |g_1|^2] - z [|f_1|^2 - 2|g_1|^2 + 6\delta \text{Re}(g_1 g_2^*)] \} \\
 I_1(z) &= [|f_1|^2 + |g_1|^2] - z [|f_1|^2 + 2\delta \text{Re}(g_1 g_2^*)] \\
 I_2(z) &= -I_6(z) = 2z(g_1 - \delta g_2)^2 \\
 -I_3(z) &= I_5(z) = 2\delta z(1-z)^{\frac{1}{2}}(f_1 + f_2)(g_1 - \delta g_2) \\
 I_4(z) &= (1-z)^{\frac{1}{2}} [\text{Re}(f_1 g_1^*) - \delta z \text{Re}(f_1 g_2^*)] \\
 I_7(z) &= 2z^{\frac{1}{2}} \{ \text{Re}[g_1(g_1 - \delta g_2)^* + \delta f_1(f_1 + f_2)^*] - \delta z \text{Re}[f_1(f_1 + f_2)^* + g_1 g_2^*] \} \\
 I_9(z) &= -2z^{\frac{1}{2}}(1-z)^{\frac{1}{2}} \{ \text{Re}(f_1 g_1^*) + \delta \text{Re}[(f_1 + f_2)g_1^* - f_1 g_2^*] \}.
 \end{aligned} \tag{4}$$

It is clear that whereas the measurement of I_2 , I_3 , I_5 , I_6 and I_9 as functions of z will not yield more information on the form factors as compared to the integrated case ($\langle I_i \rangle$ as discussed in I), the z -spectrum of (dR/dz) , I_1 , I_4 and I_7 can be used to isolate certain combinations of form factors which are not available in the integrated data. This is valuable especially in connection with extracting information on the form factors f_2 and g_2 which only occur to order δ . In the integrated data (Table I on I), these form factors are invariably masked by the zeroth order terms consisting of f_1 and g_1 . To determine f_2 and/or g_2 would require either very high statistics or complete experiments which measure simultaneously a large number of the asymmetries discussed in I. On the other hand, if the z -spectrum is measured, such small effects can be separated from the dominant terms from their z -dependence as, for instance, in $I_4(z)$, Eq. (4).

The decay rate z -spectrum ($d\Gamma/dz$) is undoubtedly the easiest to measure among all possibilities listed in Eq. (4). It is interesting to note that: (i) the overall factor $(1-z)^{\frac{1}{2}}$ (in some sense the "allowed spectrum" in the usual terminology) is relatively smoothly varying as compared to the linear function in z within the curly brackets from which information on the form factors is to be extracted. This is to be contrasted with the usual lepton energy spectrum from which a rapidly varying $E^2(E_{\max}-E)^2$ "allowed spectrum" had to be divided out in order to separate the form factors²; (ii) the coefficient of z within the curly brackets is a fortunate combination because the g_2 term has a large coefficient and, at least for Λ beta-decay, the combination $(|f_1|^2 - 2|g_1|^2)$ is expected to be small if Cabbibo theory is correct.³ This provides a very promising method to test the Cabbibo theory and detect the possible existence of second class currents (g_2) in Λ beta decay. This method can be applied in experiments both with polarized or unpolarized Λ in the initial state.

The asymmetry of particle B with respect to the A-spin vector (number of events with $0 < \psi < \frac{\pi}{2}$ minus that with $\frac{\pi}{2} < \psi < \pi$) as a function of z is

$$\begin{aligned} \frac{dA_B(z)}{dz} = & [G^2 M_-^5 / 24 \pi^3 (1+\delta)^3] (1-z) \\ & \times \{ -\text{Re}(f_1 g_1^*) + z \text{Re}(f_1 g_2^* + 2(f_1 + f_2) g_1^*) \} \end{aligned} \quad (5)$$

The second term in the curly bracket in (5) as well as that of I_7 in (4) are sensitive to f_2 provided either one assumes second class current

is absent or else knows the value of g_2 from dr/dz and I_4 .

It should be quite obvious that the method proposed above for extracting information on f_2 and g_2 is entirely analogous to that used to verify the CVC hypothesis in nuclear beta decay.² The only difference lies in the fact that we are proposing to look at the q^2 -spectrum instead of the conventional electron energy spectrum. The advantages for this method have already been commented on in a previous paragraph. We add that q^2 is the more natural variable to use also because possible anomalous rapid dependence of the form factors on q^2 can be easily included should the experimental data call for it. We also remark that q^2 is simply related to the energy of particle B in the rest frame of A.

One may wonder what about the spectra of the other asymmetries, say, A_e and A_v . Do they yield new information on the form factors? It turns out the variable q^2 is not the natural variable to describe these quantities. Consequently, the q^2 -spectra for these are not as simple as Eqs. (4) and (5), containing logarithmic functions among other things. It is not hard to see that, provided the q^2 -dependence of the form factors are neglected, the spectrum of $A_e(A_v)$ are simple in the variable $E_e(E_v)$ and useful information on the form factors can be extracted in the same manner as described above.

The results of this note together with those of I, in principle, exhaust all the information contained in polarized hyperon decay. We close on a note of caution: these results are all subject to modifications due to radiative corrections of an uncertain magnitude. The need for a reliable calculation of these corrections can hardly be overemphasized.

1. P.H. Frampton and Wu-ki Tung, Phys. Rev. (to be published).
2. Y.K.Lee, L.W. Mo and C.S. Wu, Phys. Rev. Letters 10, 253 (1963).
3. The present best fit of Cabbibo theory to hyperon decays yields for Λ beta-decay $g_1/f_1 = 0.74$. See, for example, H. Filthuth, Topical Conference on Weak Interactions, CERN (1969) (unpublished).
4. E_e and E_ν are the energies of the electron and neutrino respectively in the rest frame of A. These are also equivalent to the invariant variables $(p_B + p_\nu)^2$ and $(p_B + p_e)^2$ respectively.