LEPTON PAIRINGS IN THE TWO-NEUTRINO THEORY

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In this note we will discuss some possible implications of the assumption that two distinct neutrinos are involved in the weak interactions. In particular, we consider the possibility that the association of the neutrinos with charged leptons in strangeness-changing decays is different from the pairing in strangeness-conserving decays. We will see that this possibility, if fulfilled, would have important consequences for proposed inverse neutrino reactions.

We recall that the existence of two neutrinos was assumed in order to forbid the decay $\mu \to e + \gamma$ by a selection rule,[1] according to which the μ and e are assigned different values of some quantum number. In order to make this consistent with the ordinary μ decay, two distinct neutrinos ν_1 and ν_2 with the same helicity are introduced, and the μ decay is assumed to be of the form

$$\mu^- \to e^- + \bar{\nu}_1 + \nu_2. \tag{1}$$

This follows in a natural way from the common assumption that all strangeness-conserving decays arise from an interaction of the form $J^\dagger J$, provided that $J = \bar{n}p ... + e^- \nu_1 + \mu^- \nu_2$. Such a structure implies also that the π decays are

$$\pi^+ \to e^+ + \nu_1, \tag{2}$$

$$\pi^+ \to \mu^+ + \nu_2. \tag{3}$$

These processes will not lead to $\mu \to e + \gamma$ to any order.[2]

It has been usually assumed that the pairings $(\mu\nu_2)$ and $(e\nu_1)$ are, in fact, universal and also occur in strangeness-changing reactions. The purpose of this note is to point out that if two neutrinos exist at all, there is the alternative possibility that in decays with $\Delta S = \pm 1$, the pairings $(e\nu_2)$ and $(\mu\nu_1)$ may occur. In such a theory the two-body leptonic decays of the K^+ would be

$$K^+ \to \mu^+ + \nu_1, \tag{4}$$

$$\to e^+ + \nu_2. \tag{5}$$

We will refer to such decays as "neutrino flip" decays. In the conventional theory the decays would instead be

$$K^+ \to \mu^+ + \nu_2, \tag{6}$$

$$\to e^+ + \nu_1. \tag{7}$$

Clearly, no direct experimental evidence exists at present to decide between the reactions (4), (5) and (6), (7), although the arguments on forbidding $\mu \to e + \gamma$ to all orders implies that they cannot coexist. If the reactions (4), (5) rather than (6), (7) occur, there will be important experimental consequences, some of which we indicate here.

(1) If high-energy neutrinos are obtained from the decay of a beam of positive pions, which has a "contamination" of positive K mesons, the net neutrino beam would be a mixture of ν_1 and ν_2 and therefore could generate both the reactions

$$\nu_1 + n \to e^- + p, \tag{8}$$

and

$$\nu_2 + n \to \mu^- + p. \tag{9}$$

We have been informed[3] that in neutrino experiments in progress, the K contamination of the pion beam may be $\sim 20\%$. In the presence of neutrino flip decays this might lead to a sizable electron production. If an experiment is performed with neutrinos from a contaminated beam and no electrons are found, it would not only establish the two-neutrino theory, but also rule out the existence of neutrino flip K decays. Conversely, the mere observation of electrons produced by neutrinos would disprove the two-neutrino theory only if a "pure" pion beam was the source of neutrinos. (We neglect the one neutrino in 10^4 coming from $\pi \to e + \nu$ decay.)

(2) A related point is the availability of high-energy ν_1's from K^+ decay if the neutrino flip decay (4) occurs. Such high-energy ν_1's are not obviously available from any other source and would be a good tool in studying the symmetry between muon and electron interactions, by comparing for example the reactions (8) and (9). It will therefore be useful in this connection to be able to distinguish experimentally between inverse neutrino events induced by K^+ neutrinos and by π^+ neutrinos For this purpose kinematic discriminations in a "contaminated" beam may be sufficient.

(3) The occurrence of neutrino flip K decays necessarily implies the occurrence of neutrino flip in hyperon-lepton interactions with $\Delta S = \Delta Q$. This means that in a neutrino absorption experiment, where the neutrinos are known to be of one type, the charged leptons produced with hyperons will not be the same as those produced with nu-

cleons. In particular the reactions

$$\bar{\nu}_2 + p \to \Lambda^0 + e^+, \tag{10}$$

$$\bar{\nu}_1 + p \to \Lambda^0 + \mu^+, \tag{11}$$

will occur, rather than

$$\bar{\nu}_2 + p \to \Lambda^0 + \mu^+, \text{ etc.} \tag{12}$$

In addition, we would like to make some comments of a more theoretical nature.

(a) If the lepton pairings in strangeness-changing decays are indeed different than those in strangeness-conserving decays, it would suggest that leptons carry a quantum number somehow related to strangeness,[4] and that the weak leptonic interactions are characterized by a selection rule involving both of these numbers. In this connection we mention that the reactions (4), (5) also imply the existence[5] of $\mu^+ \to e^+ + \nu_2 + \bar{\nu}_1$. These points will be taken up elsewhere.

(b) Unless special parity structures of the leptonic, strangeness violating, couplings prevail, it follows that if the K_{l2} modes (4) and (5) do show neutrino flip, all $\Delta S/\Delta Q = +1$ transitions do the same. Thus in the K_{l3}^+ decays and in the $(|\Delta S| = 1)$ β and μ decays of Λ, Σ^-, and Ξ^- we would expect also (e, ν_2) and (μ, ν_1) pairings. The same is true in $K^0 \to \pi^- + e^+ + \nu_2$. If $\Delta S/\Delta Q = -1$ transitions occur, it is evidently impossible to determine the nature of the lepton pairing in such reactions from Eqs. (4) and (5). To reconcile the absence[6] of nonleptonic $\Delta S = 2$ transitions with a relatively simple current-current structure, it is attractive to consider the possibility that, if reactions with $\Delta S/\Delta Q = -1$ take place at all, the pairing is (e, ν_1), (μ, ν_2). In this case we would have

$$K^0 \to \pi^- + e^+ + \nu_2 \tag{13}$$

$$\to \pi^+ + e^- + \bar{\nu}_1, \tag{14}$$

$$\bar{K}^0 \to \pi^+ + e^- + \bar{\nu}_2 \tag{15}$$

$$\to \pi^- + e^+ + \nu_1. \tag{16}$$

We now assume CP invariance. Then regardless of the relative pairings in the reactions (14), (16) as compared to (13), (15), we have

$$R_1(\pi^-) = R_1(\pi^+), \tag{17}$$

$$R_2(\pi^-) = R_2(\pi^+), \tag{18}$$

where R_1 (R_2) denote the total rate of decay of K_1 (K_2) into the π with charge as indicated plus the corresponding electron-neutrino pair (and likewise for the μ-neutrino pair). We now consider the following three instances.

(i) No $\Delta S/\Delta Q = -1$ transitions. We have now in addition

$$R_1(\pi^-) = R_2(\pi^-). \tag{19}$$

(ii) $\Delta S/\Delta Q = -1$ transitions occur and the same lepton pairings (e, ν_2), (μ, ν_1) appear in both $\Delta S/\Delta Q = \pm 1$. This means that in Eqs. (14) and (16) $\bar{\nu}_2$ and ν_2 occur, respectively, rather than $\bar{\nu}_1$ and ν_1. The relation (19) is now in general not true due to different coherence effects in K_1 as compared to K_2 decays.

(iii) $\Delta S/\Delta Q = -1$ transitions occur and the lepton pairing is as indicated in Eqs. (13)-(16). Now, for example, the K_1 decay into $\pi^- + e^+ +$ neutrino is the incoherent superposition of the channels (13) and (16). Thus the rate is one half the sum of the partial rates. As a result the relation (19) is true even in the presence of (CP-invariant) $\Delta S/\Delta Q = \pm 1$ transitions.[7] Thus we have here the possibility of an experimental distinction between the cases (ii) and (iii). Observe also that if the $\Delta S/\Delta Q = +1$ transitions satisfy more specifically $|\Delta T| = \frac{1}{2}$, then the following conclusion is immediate: If $\Delta S/\Delta Q = -1$ transitions occur, with pairings as in Eqs. (14) and (16), then the ratio of rates $(K_2^0 \to \pi^\pm + e^\mp + \nu)/(K^+ \to \pi^0 + e^+ + \nu)$ is larger than two.

It should be noted that these last results depend only on the lepton pairing in $\Delta S/\Delta Q = +1$ relative to $\Delta S/\Delta Q = -1$. It is independent of the lepton pairing in $\Delta S/\Delta Q = +1$ relative to strangeness-conserving reactions.

In addition it should be emphasized that if $\Delta S/\Delta Q = -1$ involves (e, ν_1) and (μ, ν_2), as in Eqs. (14) and (16), then for example $\nu_2 + n \to \Sigma^+ + e^-$ remains forbidden, while for pairing (e, ν_2), (μ, ν_1) this reaction is allowed.

(c) It has been surmised that all the weak interactions are generated by a sum of product of currents such as $(\mathcal{J} + j + s)^\dagger \cdot (\mathcal{J} + j + s) + (j_0 + s_0)^\dagger \cdot (j_0 + s_0)$. This extension of the universal Fermi interaction to include strangeness-changing processes has sometimes been questioned, because of the absence of neutral lepton currents and because of the slowness of hyperon decay into leptons compared to the universal rates.[8] Regardless of these problems we would like to emphasize that the existence of the neutrino flip K decays would rule out this particular current-current structure, since different lepton currents occur in $\Delta S = 0$ decays than in $|\Delta S| = 1$ decays. Of course, a more complicated current structure can be envisaged.

(4) If all weak interactions including nonleptonic ones are considered to all orders of perturbation theory, then the absence of $\mu \to e + \gamma$ decay rules

out neutrino flip K decays.[9] This follows because the K meson can convert into a pion through virtual weak nonleptonic interactions, and therefore the chain $\mu \to K + \nu_1 \to \pi + \nu_1 \to e + \gamma$ can occur to third order in weak interactions. From this standpoint there is therefore a cogent objection to our proposal, if the cutoff of weak interactions is very large. However, we believe that this theoretical question is sufficiently open to warrant a direct experimental test of the existence of neutrino flip.

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After this note was submitted, Dr. B. d'Espagnat kindly brought to our attention a preprint[10] by Dr. S. Bludman in which the possibility of neutrino flip for a $\Delta S = \Delta Q$ is already considered.

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$\Lambda\pi$ RESONANCE AND s-WAVE K^--p REACTIONS*

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The Y_1^* or $\Lambda\pi$ resonance at 1385 Mev has been observed by several experimental groups.[1] One of the theoretical explanations of the Y_1^* is that it is a quasi-bound state of the s-wave $\bar{K}N$ system. In fact, Dalitz and Tuan,[2] from their rough, constant-scattering-length analysis of the s-wave K^-p data, predicted that such a resonant state might exist. Discovery of the Y_1^* led to a discussion by Ross and Shaw[3] of the possibility of putting the association of the Y_1^* with the $\bar{K}N$ s state to a detailed test by means of an effective-range analysis, and as a result determine the KYN parities.

The purpose of this note is to report on an extensive survey of effective-range solutions of the s-wave K^-p data. The results can be summarized as follows: Assuming that the Y_1^* is associated with K^-p s state, the only acceptable solutions found were for the $\Sigma\pi$ channel in a p state (thus even $K\Sigma N$ parity), whereas the $\Lambda\pi$ channel could be either in an s or p state. In addition, among three different sets of effective ranges, only the one corresponding to a moderately short "range of forces," i.e., 0.4 f, led to satisfactory solutions.

The scattering amplitudes T_{ij} for a system of n coupled two-particle channels in a given state of total angular momentum J, z component J_z, isotopic spin I, parity P, etc., can be expressed as[4]

$$T = k^{l+1/2}(M - ik^{2l+1})^{-1}k^{l+1/2}. \qquad (1)$$

The partial cross section from channel i to chan-