LEPTON γ_5 SYMMETRY IN WEAK INTERACTIONS AND IN $\Delta S = -\Delta Q$ DECAY MODES

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The assumptions of an additive conservation law of leptonic charge and of definite chiralities of the electron and muon in weak interactions determine uniquely the lepton pairs (ν_e, e^-) and (ν_μ, μ^-) in the four-fermion interaction with baryons only in the case of V-coupling. The possible violation of V-coupling in the $\Delta S = -\Delta Q$ decay modes of strange particles, and hence the possible participation of lepton pairs of the forms $(\tilde{\nu}_\mu, e^-)$ and $(\tilde{\nu}_e, \mu^-)$ in weak interactions, is discussed.

THE recent experiment at Brookhaven[1] which has disclosed an asymmetry of electrons and muons with respect to neutrinos originating from pion decays, is a brilliant experimental confirmation of the two-neutrino hypothesis which has been discussed in recent years[2-7] (further references are given in [1]).

In a previous paper[5] the author has obtained the two neutrinos from a classification of neutral massless fermions with respect to the sign of the leptonic charge and chirality (the eigenvalues of the operator γ_5)[1)]:

$$\begin{array}{ccccc} & \nu_e & \nu_\mu & \tilde{\nu}_e & \tilde{\nu}_\mu \\ l & +1 & -1 & -1 & +1 \\ \gamma_5 & +1 & +1 & -1 & -1 \end{array} \quad (1)$$

In conformity with the work of Marshak and Sudarshan[8] it has been assumed in [5] that the massive leptons (e and μ) also possess definite chiralities in weak interactions, in the sense that each occurs in the weak interaction Lagrangian always with the same factor $(1+\gamma_5)$ or $(1-\gamma_5)$ and that the Lagrangian is invariant with respect to the following transformations[2)]:

$$e^{\mp} \to \pm\gamma_5 e^{\mp}, \qquad \mu^{\mp} \to \pm\gamma_5 \mu^{\mp}. \quad (2)$$

In the case of V-coupling the γ_5 symmetry implies conservation of the lepton chirality in weak interactions, introducing a new additive quantum number in addition to electric and leptonic charge. If one now attributes different leptonic charges to electrons and muons of equal electric charge (following the proposals of Konopinski and Mahmoud[10] and Zel'dovich[11]), i.e.,[5]

$$\begin{array}{ccccc} & e^- & \mu^- & e^+ & \mu^+ \\ l & +1 & -1 & -1 & +1 \\ Q & -1 & -1 & +1 & +1 \end{array}, \quad (3)$$

then the conservation of the electric and leptonic charges and chirality will imply uniquely that only lepton pairs of the form

$$L_1 = (\nu_e, e^-), \qquad L_2 = (\nu_\mu, \mu^-) \quad (4)$$

must participate in all weak interactions (we do not consider here neutral currents). In particular, the form of the muon decay interaction will be uniquely determined as:

$$\mu^- \to e^- + \tilde{\nu}_e + \nu_\mu \quad (5)$$

and processes of the form

$$K^0 \to \mu^+ + e^-, \qquad e^- + 2p \to \mu^+ + 2n, \quad (6)$$

will be forbidden, although they conserve leptonic charge alone.

However it is important to note that owing to the definition (3) of leptonic charge, the conservation laws of the charges and γ_5-invariance determine uniquely both the muon decay interaction (5) and the form of the four-fermion muon decay interaction, independently of the assumption of V-coupling. Indeed, using the Fierz identities, it is easy to see that the two expressions of the four-fermion interaction Hamiltonian which are allowed by the conservation of the charges and by γ_5-invariance

$$H_V \sim (\bar{\nu}_\mu \gamma_\alpha (1+\gamma_5)\mu^-)(\overline{e^-}\gamma_\alpha (1+\gamma_5)\nu_e), \quad (7)$$

[1)]Cf. also the papers by Schwinger,[2] Nishijima[3] and Kawakami[4]. In distinction from [5], in these papers two neutrinos are already connected a priori in a "rigid" manner with the electron and muon, respectively (see below).

[2)]The statement (2) is essentially based on the assumption that in determining the form of the basic weak interaction all leptons can be considered massless (cf. [9]).

$$H_S \sim (\bar{\tilde{\nu}}_e (1+\gamma_5)\mu^-)(\bar{e}^-(1-\gamma_5)\tilde{\nu}_\mu) \quad (8)$$

are identical with each other. The tensor interaction

$$H_T \sim (\bar{\tilde{\nu}}_e \gamma_\alpha \gamma_\beta (1+\gamma_5)\mu^-)(\bar{e}^- \gamma_\alpha \gamma_\beta (1-\gamma_5)\tilde{\nu}_\mu), \qquad \alpha \neq \beta \quad (9)$$

vanishes as a consequence of Eq. (2). This means that within the framework of leptonic interactions only (the muon decay theory) one is allowed to consider with equal rights both the vector and scalar currents.

The situation is different for the interaction of leptons with baryons. It is easy to see that in this case giving up the assumption of V-coupling would lead to a loss of uniqueness of the lepton pairings (4). In other words, if one does not impose V-coupling, the conservation laws of the charges and γ_5-invariance would allow not only the pairings (4) but also the following lepton pairings:

$$L_3 = (\tilde{\nu}_\mu, e^-), \qquad L_4 = (\tilde{\nu}_e, \mu^-). \quad (10)$$

Thus, for instance, the beta-decay Hamiltonian could be of the form

$$H_\beta \sim (\bar{p}(1 \pm \gamma_5) n)(\bar{e}^-(1-\gamma_5)\tilde{\nu}_\mu). \quad (11)$$

However, this possibility contradicts the experiments on angular distribution and the electron asymmetry in beta decay. Thus, in distinction from the theory of muon decay, a complete theory of the strangeness-conserving weak interactions of leptons and baryons is uniquely determined (and in agreement with experiment) only if one adds the independent assumption of V–A-coupling to the conservation of electric, baryonic and leptonic charge and γ_5-invariance.

The conclusion that in the leptonic interactions of strange particles with $\Delta S = +\Delta Q$ the coupling is also of the V–A type follows less definitely from experiment [8]. However, the possibility is not excluded that the (V–A) coupling is not valid for the recently discovered [12] strange particle decays with a strangeness change $\Delta S = -\Delta Q$. This would not contradict a limited universality, since, according to [13] a combination of $\Delta S = +\Delta Q$ currents is impossible (the absence of transitions with $\Delta S = 2$).

Marshak and Sudarshan [8] were the first to note that the (V–A) coupling in the four fermion interaction of any four particles [8,14] is a consequence of the requirement of invariance with respect to independent γ_5-transformations for each particle. Such an assertion is however ambiguous, since it is not clear what is meant by "particle," or in other words to what to connect the sign of chirality, to the electric charge, as in Eq. (2), or to the leptonic (baryonic) charge. This ambiguity is removed in part in the γ_5-classification of lepton doublets proposed in [9], which generalizes the lepton classification (1)–(3). It follows from this classification that in the absence of renormalizations, the $\Delta S = -\Delta Q$ baryon currents can be only scalar or tensorial and cannot be vectorial (owing to the different chiralities of the nucleon and of the Σ^+ hyperon). It is a characteristic feature that the coupling of these currents to the leptonic currents can only be scalar, since the tensor coupling vanishes.

In the present paper we consider the consequences of the assumption that in leptonic interactions the $\Delta S = +\Delta Q$ and $\Delta S = -\Delta Q$ currents of the strongly interacting particles, are vectorial and scalar (or tensorial) respectively. In this case the $\Delta S = -\Delta Q$ leptonic decays of strange particles should contain the leptonic pairings (10), i.e., the electron should appear together with the muonic antineutrino $\tilde{\nu}_\mu$ and the muon with the electronic antineutrino $\tilde{\nu}_e$, e.g.,

$$K_1^0 \to \pi^+ + e^- + \nu_\mu. \quad (12)$$

A decisive test of this assumption could be obtained in high energy neutrino experiments in the reactions

$$\tilde{\nu}_\mu + n \to e^- + \Sigma^+, \qquad \nu_\mu + p \to n + K^0 + e^+, \quad (13)$$

$$\tilde{\nu}_e + n \to \mu^- + \Sigma^+, \qquad \nu_e + p \to n + K^0 + \mu^+. \quad (14)$$

At present the reactions (13) could possibly be observed experimentally, since their threshold differs only slightly from the threshold of the reaction which has already been observed in Brookhaven:

$$\tilde{\nu}_\mu + p \to n + \mu^+, \quad (15)$$

and their cross sections are possibly by one or two orders of magnitude smaller.

In addition to the neutrino experiments at high energies, an experimental test of the hypothesis could be obtained from an investigation of the decays of $K^0_{1,2}$ mesons:

$$K_1^0 \to \pi^\pm + e^\mp + \nu, \quad (16)$$

$$K_2^0 \to \pi^\pm + e^\mp + \nu. \quad (17)$$

Owing to the absence of interference between the decays of the K^0 and $\tilde{K}^0$ components of $K^0_{1,2}$ the total probabilities of the K^0_1- and K^0_2-meson decays (16) and (17) must be equal. Apparently experimental data [12] point to the absence of such an equality.

The presence of S- or T-coupling in the $\Delta S = -\Delta Q$ decay modes of strange particles should also show up in the K_{e3} and $K_{\mu 3}$ decays of type

(17) (cf. [16,17]). The existing experimental data[16] speak in favor of V-coupling in these processes, but apparently do not allow to rule out an admixture of (S, T)-coupling of the order of 30—40%, which does not contradict the experimental data regarding the relative probabilities of the $\Delta S = +\Delta Q$ leptonic decays[12]. An increase of the accuracy of measurements of the angular correlation of leptons in these experiments would be desirable, especially for angles $\theta > \pi/2$ [17]. In case a violation of the V-coupling exists in any weak interaction process (as well as in the case of a nonvanishing neutrino mass) transitions $\nu_e \longleftrightarrow \widetilde{\nu}_\mu$ would be possible in higher orders of the weak interaction constant.

Should it be proved experimentally that the leptonic $\Delta S = -\Delta Q$ modes of the strange particles are, like the other interactions, of the vector type, then under the assumptions (1)—(3) made above, this would imply that the lepton pairings (4) are the only ones possible in all weak processes. In this case the predictions of the scheme of weak interactions with one leptonic charge will coincide with the predictions of the scheme with two leptonic charges (cf. [18]).

If the weak interactions proceed via intermediate bosons, there should exist, besides the vector bosons, also scalar bosons coupled to the leptonic currents and to the $\Delta S = -\Delta Q$ currents of the strongly interacting particles, e.g.,

$$H_s = \tfrac{1}{2} g_V \left[(\bar{n}(1-\gamma_5)\Sigma^+) + (\bar{e}^-(1-\gamma_5)\widetilde{\nu}_\mu) + (\bar{\mu}^-(1-\gamma_5)\widetilde{\nu}_e) \right] B^- + \text{c.c.} \quad (18)$$

It has been assumed here for estimating purposes that the coupling constant of the scalar bosons to the baryon and lepton currents is one half of the coupling constant g_V between the vector bosons and the conserved vector current of the strongly interacting particles. At the same time it is necessary to consider that the coupling constant of the vector bosons to the leptonic currents is also equal to $g_V/2$, in order to maintain the equality of the effective coupling constants in beta decay and in muon decay[3)].

If the weak interactions are mediated by bosons, then the muonic neutrinos can also generate electrons in collisions with nuclei in association with scalar bosons, in the following processes:

$$\nu_\mu + Z \to Z + e^+ + B^-, \qquad \widetilde{\nu}_\mu + Z \to Z + e^- + B^+. \quad (19)$$

The generation of muons in association with vector bosons will be a competing process.

The assumption that in the strangeness-changing processes the electron could be associated with a muonic neutrino and the muon with an electronic neutrino has been made in the papers by Bludman[19] and Feinberg, Gürsey, and Pais[15]. The present scheme differs from the ones mentioned in the following essential conclusions.

1. The only possible lepton pairings are of the forms (4) and (10), but not (ν_μ, e^-) and (ν_e, μ^-) as considered in [19,15].

2. The "anomalous" pairs (10) interact with the $\Delta S = -\Delta Q$ currents but not with the $\Delta S = +\Delta Q$ currents.

3. The leptonic currents which contain the pairs (10) are not vector currents but scalar or tensor currents. The same is true for the $\Delta S = -\Delta Q$ baryonic currents.

4. In [18,15] two types of muon decay are possible: $\mu^- \to e^- + \widetilde{\nu}_e + \nu_\mu$ and $\mu^- \to e^- + \nu_e + \widetilde{\nu}_\mu$ and in the present case only one is possible, namely the first. Due to this fact in those schemes the process $\mu \to e + \gamma$ is possible in higher orders whereas in the present scheme this process is rigorously forbidden.

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Note added in proof (March 14, 1963). Should it be proved experimentally that the $\Delta S = -\Delta Q$ baryon currents are indeed scalar or tensorial in character and that the total probabilities of the decays (16) and (17) are not equal (the existence of interference between K^0 and $\widetilde{K}^0$ decays), this would mean that if V-coupling is violated the chiralities of the electron and muon change signs, and therefore, in principle, the weak interactions could be a source of the bare mass of these particles.

3)Such a choice of the coupling constants of the lepton currents with the vector and scalar bosons, which satisfies the condition of equality of the effective coupling constants in beta decay and muon decay, is symmetric but is not the only one possible.

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