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IS ONE OF THE LEPTON QUANTUM NUMBERS MULTIPLICATIVE ?

Nguyen Van Hieu and B. Pontecorvo  
 Joint Institute for Nuclear Research  
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As is well known, a single additive lepton quantum number that assumes only three values (-1, 0, +1) is insufficient for a description of the aggregate of experimental data on weak interaction processes in which leptons take part. We can consider different possibilities, among which we mention the following:

1. There are two different additive lepton charges - muonic and electronic. From the point of view of the experiment proposed in the present note, this alternative does not differ from the case when there is only one additive lepton charge, whose signs are opposite for  $\mu^-$  and  $e^-$  [1].

2. There is one additive lepton charge, the values of which for  $e^-$ ,  $\nu_e$  and  $\mu^-$ ,  $\nu_\mu$  are different (say +1 for  $e^-$ ,  $\nu_e$  and +2 for  $\mu^-$ ,  $\nu_\mu$ ) [2].

3. There is only one additive lepton charge  $l$  (say +1 for  $\nu_e$ ,  $\nu_\mu$ ,  $e^-$ ,  $\mu^-$  and -1 for  $\bar{\nu}_e$ ,  $\bar{\nu}_\mu$ ,  $e^+$ ,  $\mu^+$ ) and one multiplicative [3] lepton number  $M$  equal to +1 for  $\nu_e$ ,  $e^-$ ,  $\bar{\nu}_e$ ,  $e^+$  and -1 for  $\nu_\mu$ ,  $\mu^-$ ,  $\bar{\nu}_\mu$ ,  $\mu^+$ .

Alternative 3 is the least rigorous of the foregoing possibilities, since it permits, in principle, muonium  $\approx$  antimuonium transitions [4]. It calls for a value +1 for  $M$  in all particles that are not leptons (see, for example, the decay  $\pi^+ \rightarrow \mu^+ + \nu_\mu$  etc.) and it therefore seems to us quite artificial. In addition, it is not compatible with notions of Feynman and Gell-Mann [5] concerning the interaction of two currents. However, only experiment can answer the question whether alternative 3 is realized in nature.

To clarify the question of the existence of a multiplicative lepton number, it was proposed to study experimentally the oscillations of the muonium  $\approx$  antimuonium transition [3]. In this case, however, the required experiments are quite difficult. Besides, such oscillations are caused by a second-order interaction or by a rather exotic interaction. We propose below a concrete-experiment formulation free of these shortcomings.

Let us consider the decay of a muon, say a positive one (for reasons of experimental nature, which will be made clear in what follows). According to possibilities 1 and 2, its scheme is  $\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$ . On the other hand, if there exists a multiplicative quantum number  $M$  besides the additive charge (alternative 3), then the muon decay proceeds [3] in

in two equally valid channels:

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu, \quad (1)$$

$$\mu^+ \rightarrow e^+ + \bar{\nu}_e + \nu_\mu. \quad (2)$$

Thus, alternative 3 requires that not only  $\nu_e$ , but also  $\bar{\nu}_e$  be produced in the decay of a positive muon.

This can be verified by analyzing the neutral decay products of the muon. The extremely large decay length of moving muons makes it convenient to investigate their decay products with stopped muons. Since  $\nu_\mu$  and  $\bar{\nu}_\mu$  from the decay of stopped muons cannot interact with nucleons (their energy is smaller than the muon mass), the problem reduces to an analysis of the relative contents  $\nu_e$  and  $\bar{\nu}_e$  among the products of the decay of stopped positive muons.

It has already been shown [6] that an accelerator of protons of energy close to 700 MeV and of intensity of several hundred microamperes ("meson factory") makes it possible in principle to record neutral leptons from stopped muons. The  $\nu_e$  with energy in the region of several dozen MeV can be distinguished from the  $\bar{\nu}_e$  by an experiment of the type performed by Reines and Cowan [7]. Indeed,  $\bar{\nu}_e$  interacts with the proton in accordance with the scheme

$$\bar{\nu}_e + p \rightarrow n + e^+, \quad (3)$$

whereas the  $\nu_e$  cannot cause the reaction

$$\nu_e + p \rightarrow n + e^+.$$

If we use for the registration of neutral leptons a deuteron-containing target, then it is possible in principle to record interactions of both  $\bar{\nu}_e$  and  $\nu_e$  ( $\bar{\nu}_e + d \rightarrow e^+ + n + n$ ;  $\nu_e + d \rightarrow e^- + p + p$ ). However, the organization of such an experiment is not a simple matter. A more convenient organization is one in the manner of Reines and Cowan, with hydrogen-containing scintillators, the registration of the interactions between the  $\bar{\nu}_e$  and the protons being proof of the existence of one multiplicative lepton number.

What other sources of  $\bar{\nu}_e$  can produce a background in such experiments? In order to estimate this, let us assume that a proton beam, say of energy 700 MeV, passes through a long opening deep into an iron block serving simultaneously as a target (pion source) and a shield for all radiation except neutron leptons. The protons, the pions, and the muons produced by pion decay are slowed down. The number of pions of both polarities decaying in flight is insignificant, and furthermore the number of  $\bar{\nu}_e$  produced in this case ( $\pi^- \rightarrow e^- + \bar{\nu}_e$ ) can be neglected. The same can be said of the number of muons decaying in flight. The stopped positive pions produce, with unity probability, positive muons which are also stopped. On the other hand, negative pions are captured upon stopping by the nuclei and do not produce slow muons. Thus, the total number of stopped negative muons is small. In addition, stopping of negative muons in matter produces, as is well known, mostly  $\nu_\mu$  ( $\mu^- + A \rightarrow \nu_\mu + A'$ ). We see thus that the background of the  $\nu_e$  is extremely small in the experiment under consideration, all the more since the sought effect is on the order of unity.

This proposal is published because "meson factories" are soon to be constructed, and the planning of shields for experiments with beams of neutrinos from stopped mesons should already be undertaken now. We note in conclusion that, regardless of the search for the multiplicative quantum number, the analysis of the neutral products of muon decay is of independent interest.

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#### CONCERNING (V + A) CURRENTS IN WEAK INTERACTIONS OF ELEMENTARY PARTICLES

E. M. Lipmanov and N. V. Mikheev  
 Volgograd Pedagogical Institute  
 Submitted 15 December 1967  
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The model proposed by one of the authors [1,2] for weak interactions of elementary particles with one lepton charge and broken (V ± A) symmetry (with domination of (V - A)) leads to a large number of consequences that can be used for experimental searches of (V + A) currents and to establish the upper limit of the admixture of (V + A) coupling in the current-current weak-interaction Lagrangian. A method was described in [2] for constructing effective Lagrangians of different weak processes in which leptons participate in the presence of (V + A) coupling, and several effects were considered in known weak processes such as μ, π, and β decays and experiments with high-energy neutrinos. In this paper we consider the effect of (V + A) currents in the exact form of the spectrum and angular correlations of μ-decay electrons in the entire range of momentum variation, from p = 0 to p = p<sub>max</sub>. The discussion of this effect, in which interference takes place between the (V - A) and (V + A) couplings, has become more timely in connection with recently undertaken measurements of the μ-decay electron spectrum at decreasing energies [3].

Using the expression for the μ-decay Lagrangian from [2]

$$L_{\mu} = \frac{g}{\sqrt{2}} (\bar{\nu}_{\mu} \gamma_{\alpha} (1 + \gamma_5) \mu) (\bar{e} \gamma_{\alpha} (1 + \gamma_5) \nu_e) - \sqrt{2} g_1 (\bar{\nu}_{\mu} (1 - \gamma_5) \mu) (\bar{e} (1 + \gamma_5) \nu_e), \quad (1)$$

we get with the aid of the standard projection-operator technique [4] for the differential probability of the decay of a polarized muon at rest decaying on an electron with energy  $\epsilon = E/E_{\max}$  and momentum  $x = p/p_{\max}$

$$\frac{4\pi}{d\Omega} \frac{dw}{d\epsilon} = \frac{m_{\mu}^5 G^2}{192\pi^3} x \epsilon \{ D_0 + D_1 (\vec{\sigma}_{\mu} n) + D_2 (\vec{\sigma}_e n) + D_3 (\vec{\sigma}_{\mu} n) (\vec{\sigma}_e n) + D_4 [(\vec{\sigma}_{\mu} \vec{\sigma}_e) - (\vec{\sigma}_{\mu} n) (\vec{\sigma}_e n)] \}, \quad (2)$$