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SOME CONSEQUENCES OF THE EXISTENCE OF MORE THAN TWO NEUTRINOS

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The recent experiment at Brookhaven has demonstrated that there exist at least two types of neutrinos, ν_1 and ν_2, associated with respectively the electron and muon. Theoretical arguments for this assumption existed prior to the experiment, as a means of explaining the absence of the process 1), in which a meson turns into an electron by the virtual emission and reabsorption of a neutrino,

$$\mu \to e + \gamma \tag{1}$$

To describe the existence of two neutrinos and of the muon and electron, Bludman 2) and Feinberg et al 3) postulated the existence of a selection rule, associated with a "muon" quantum number, which could be either multiplicative or additive in nature.

If one assumes that this new quantum number (P) is conserved in weak interactions, but strangeness (S) is not, then the same neutrinos are associated with muons and electrons in the decay of strange particles as with non-strange particles. If, on the other hand, S and P are not individually conserved, but such as the sum or the product is conserved, the rôles of the two neutrinos will be interchanged in strangeness violating decays (i.e. "neutrino flip"). This hypothesis can only be tested by experiments with neutrinos from pion decays and from kaon decays.

THEORY

We would like to investigate, in the present note, the hypothesis that there may be more than two neutrinos, and as a first step we assume that there are four, ν_1, ν_2, ν_3, ν_4. The two new neutrinos ν_3 and ν_4 are distinguished from ν_1 and ν_2 by some quantum number and, in order not to increase this number in physics, we will identify this quantum number with strangeness.

For this assignment to have any sense, we also require that strangeness is conserved in leptonic weak interactions. It is also clear that this assignment is in no way unique. One was to do it is to assign $S = -\frac{1}{2}$ to the negative charged leptons and to ν_1 and ν_2, and $S = +\frac{1}{2}$ to ν_3 and ν_4. With this assignment the $\Delta S = \Delta Q$ rule necessarily follows in the leptonic decays. One might from symmetry like to predict the existence of a set of "strange" charged leptons with $S = +\frac{1}{2}$ to match the strange neutrinos ν_3 and ν_4. Another possible assignment would be to give the charged leptons and ordinary neutrinos zero strangeness, whereas the neutrinos ν_3 and ν_4 would have strangeness +1. This again leads to the $\Delta S = \Delta Q$ rule, but leaves the possibility open that there exist two more neutrinos ν_5 and ν_6 with $S = -1$, in case of confirmation of the experimental evidence that the $\Delta S = \Delta Q$ rule is violated.

The attractive idea of a current-current interaction

$$H = (J_{P\bar{N}} + J_{P\bar{\Lambda}} + J_{\nu_1 e^+} + J_{\nu_2 \mu^+}) \text{ (charge conjugate current)} \quad (2)$$

to describe all the features of the universal Fermi interaction has room only for two neutrinos, ν_1 and ν_2, which are always related to respectively electron and muon. This simple interaction has therefore to be dropped if one wants to consider either two neutrinos with neutrino flip or four or more neutrinos.

If instead one considers the interaction as mediated by an intermediate vector boson, one will in either hypothesis need two different kinds, the ordinary vector boson, $W^{\pm}$, which is coupled to the strangeness conserving baryon current $p\bar{n}$ and to the lepton currents $\nu_1 e^+$ and $\nu_2 \mu^+$, and a strange intermediate boson $B^\pm$ which is coupled to the strangeness non-conserving baryon current and to the lepton currents $e^+\nu_3$ and $\mu^+\nu_4$ in the case of four neutrinos and $e^+\nu_2$ and $\mu^+\nu_1$ in the case of two neutrinos with neutrino-flip.

Both hypothesis fail to describe the coupling between two strangeness conserving and non-conserving baryon currents, as is necessary for the non-leptonic decays of the strange particles, and this is probably their weakness. One would have to add an additional term in the interaction to describe these processes.

COMPARISON WITH EXPERIMENTAL DATA

The introduction of the strange neutrinos ν_3 and$\nu\nu_4$, combined with the strangeness selection rules, forbids processes with a change in strangeness of two, such as

$$\Xi^- \rightarrow n + \ell^- + \bar{\nu} \tag{3}$$

and some strange particle decays with neutral lepton currents, such as

$$K^0 \rightarrow \ell^+ + \ell^- \tag{4}$$

$$K^+ \rightarrow \pi^+ + \ell^+ + \ell^- \tag{5}$$

against which there is strong experimental evidence. Other decay processes with neutral lepton currents would still be allowed, such as

$$K^+ \rightarrow \pi^+ + \nu_3 + \bar{\nu}_1 \tag{6}$$

which would show up as anomalous τ' decays with a π^+ spectrum extending up to 117 Mev.

This reaction has never been observed, although extensive scanning for anomalous τ' decays has been done by emulsion and bubble chamber techniques. The present upper limit to these decays where the pion has more than the kinematic limit for τ' is $< 10^{-2}$.

Perhaps an interesting feature with the four-neutrino hypothesis is associated with the fact that there is a discrepancy of about 4% between the observed muon lifetime and the number calculated from V-A theory with UFI .

In the four-neutrino hypothesis there would exist another channel for muon to decay into an electron and a pair of strange neutrinos $\bar{\nu}_3$ and ν_4 and if one can assume that the present 4% discrepancy in the muon lifetime is actually the contribution of this channel, then it is plausible to explain that all the leptonic decays of hyperons and K mesons would be much smaller than predicted by the UFI which is indeed the case experimentally.

POSSIBLE TESTS WITH NEUTRINO INDUCED INTERACTIONS

As with the two neutrino-hypothesis, the most direct way to verify the four-neutrino hypothesis is by means of neutrino induced interactions. The four-neutrino hypothesis predicts that neutrinos from pion decay carry no strangeness and are therefore incapable of producing strange particles, whereas the neutrinos from decays of K mesons always produce single K^+ or K^0 mesons, and the anti-neutrinos K^-, $\bar{K}^0$ or hyperons.

Since it is experimentally impossible to make pure beams of two kinds of neutrinos, at present these predictions can only be tested statistically by comparing the results from runs when the relative contribution to the neutrino flux from pions and K meson decay is changed by changing the decay length. Such experiments are certainly difficult, but may be possible with the enhanced neutrino flux available in the future.

If in the coming neutrino experiments with a decay path, long with respect to the K decay length, one observes a sufficiently intense production of strange particles, there may thus be a point to check that the rate changes relatively little with the shortening of the decay path as predicted, if the event producing neutrinos originate from the K meson decays. If with the increased statistics of the next experiment some electrons are observed, the same experiment with a short decay path would simultaneously be a check on the flipped two-neutrino hypothesis.

CONCLUSION

The hypothesis that the two neutrinos associated with the electron and muon in strange particle leptonic decays are different from those in strangeness conserving decays is not in contradiction with present experimental evidence, and helps to forbid some of the processes which have not yet been found experimentally. The hypothesis predicts the $\Delta S/\Delta Q = +1$ rule to hold in leptonic decays. From the point of view of the formulation of a simple theory, the four-neutrino hypothesis suffers from the disadvantage that the simple formulation of the UFI as a current-current interaction describing all weak processes has to be abandoned and replaced by a more complicated interaction with at least three terms to describe strangeness conserving and "strangeness violating" leptonic decays and a third term to describe the non-leptonic decays, about which no predictions can be made. The universality of the interaction would then come out as a coincidence. These theoretical objections are shared with the flipped two-neutrino theory of Bludman and Feinberg, Pais and Gürsey.

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