ON TWO TYPES OF NEUTRINOS; THE ISOTOPIC SPIN OF LEPTONS, AND THE UNIVERSAL FOUR-FERMION INTERACTION

É. M. LIPMANOV

Stalingrad State Pedagogical Institute

Submitted to JETP editor May 19, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **37**, 1054-1057 (October, 1959)

The hypothesis is suggested that there exist in nature two types of neutrinos ν_1 and ν_2, which have the same longitudinal polarization but different leptonic charges, and which form, together with the electron and the μ meson, two isotopic leptonic doublets $(\nu_1 e)$ and $(\nu_2\mu)$. The leptonic charges of the electron and the μ meson are also opposite. The laws of conservation of isotopic spin, leptonic charge, and chirality uniquely determine the character of the μ decay and give selection rules that forbid various unobserved reactions involving leptons.

1. The discovery of the noninvariance of the laws of nature under mirror imaging has led to a revision of the properties of one of the most interesting of the elementary particles, the neutrino. The result has been the development of the theory of the two-component neutrino,[1-3] whose wave function is an eigenfunction of the chirality operator γ_5. The problem of the neutrino, however, cannot yet be regarded as solved. Ya. B. Zel'dovich[4] has pointed out the interesting possibility of describing the weak interactions involving leptons in terms of isotopically invariant couplings between the particle-pairs electron-neutrino (νe) (a doublet in isotopic space, denoted hereafter as l_1), muon-neutrino $(\nu\mu)$ (the doublet l_2), and proton-neutron (the doublet B). Without including hyperons* in our discussion, let us make the assumption that the Hamiltonian of the four-fermion interactions has the following form:

$$\begin{aligned} H &= g\,[(\bar{B}\boldsymbol{\tau}OB) + (\bar{l}_1\boldsymbol{\tau}Ol_1) + (\bar{l}_2\boldsymbol{\tau}Ol_2)]^2 \\ &= g\,[(\bar{B}\boldsymbol{\tau}OB)(\bar{B}\boldsymbol{\tau}OB) + (\bar{l}_1\boldsymbol{\tau}Ol_1)(\bar{l}_1\boldsymbol{\tau}Ol_1) + (\bar{l}_2\boldsymbol{\tau}Ol_2)(\bar{l}_2\boldsymbol{\tau}Ol_2)] \\ &\quad + 2g\,[(\bar{B}\boldsymbol{\tau}OB)(\bar{l}_1\boldsymbol{\tau}Ol_1) + (\bar{B}\boldsymbol{\tau}OB)(\bar{l}_2\boldsymbol{\tau}Ol_2) \\ &\quad + (\bar{l}_1\boldsymbol{\tau}Ol_1)(\bar{l}_2\boldsymbol{\tau}Ol_2)], \end{aligned} \tag{1}$$

where $\boldsymbol{\tau}$ is the vector matrix of the isotopic spin, and $O = \gamma_\mu(1 \pm \gamma_5)$. The expression (1) for the Hamiltonian excludes the unobserved decay of the μ meson into three electrons, satisfies the requirements of Lorentz and isotopic invariance and of the conservation of chirality in the weak interactions,[5] and is invariant with respect to any interchanges of the types $l_1 \rightleftarrows l_2$, $l_{1,2} \rightleftarrows B$. The expression (1) leads to the following interactions:

$$\begin{aligned} H = g\,&[(\bar{p}ON)(\bar{e}O\nu) + (\bar{N}Op)(\bar{\nu}O\mu) \\ &+ (\bar{\nu}O\mu)(\bar{e}O\nu) + \text{Herm. c.} \\ &+ (g/2)\,[(\bar{N}Op)(\bar{p}ON) + (\bar{e}Oe)(\bar{\mu}O\mu) + 2(\bar{p}Op)(\bar{\nu}O\nu) \\ &- 2(\bar{N}ON)(\bar{\nu}O\nu) - (\bar{p}Op)(\bar{e}Oe) - (\bar{p}Op)(\bar{\mu}O\mu) \\ &+ (\bar{N}ON)(\bar{e}Oe) + (\bar{N}ON)(\bar{\mu}O\mu)] \\ &+ (g/4)[(\bar{e}Oe)(\bar{e}Oe) + (\bar{\mu}O\mu)(\bar{\mu}O\mu) + 4(\bar{\nu}O\nu)(\bar{\nu}O\nu) \\ &+ (\bar{p}Op)(\bar{p}Op) + (\bar{N}ON)(\bar{N}ON)]. \end{aligned} \tag{2}$$

In addition to the first-order parity-nonconservation effects considered by Zel'dovich,[4] the Hamiltonian (2) leads to other analogous effects, for example to parity nonconservation in the scattering of electrons by electrons and positrons, to a displacement of levels of different parities in positronium, etc. A characteristic feature is that Eq. (2) does not contain the terms for scattering of neutrinos by electrons,* $(\bar{e}O\nu)(\bar{\nu}Oe)$, which were proposed by Gell-Mann and Feynman.[6] It also follows from Eq. (2) that in the four-fermion interaction there are three different constants for the three types of coupling terms, those containing four different fermions (g), two different fermions (g/2), and just one single fermion (g/4). An exception to this rule is seen in the terms containing neutrinos.

*The question of the possibility of including the hyperons in the general scheme of four-fermion interactions will be considered in another place.

*Such terms could be kept if we were to change the sign of the third term $(\bar{l}_2\tau Ol_2)$ in the first expression (1). Then, however, Eq. (2) would lack the terms for scattering of neutrinos by nucleons and by neutrinos themselves, and the symmetry of the interaction would be destroyed.

2. How plausible is the assumption of the existence of the isotopic doublets (νe) and ($\nu\mu$)? Clearly the strangest thing about this is that the same particle ν occurs in two isotopic doublets. Let us assume that we have here two different neutrinos ν_1 and ν_2, so that what we are speaking of is the two pairs $l_1 \equiv (\nu_1 e^-)$ and $l_2 \equiv (\nu_2\mu^-)$. Instead of Eqs. (2) and (1) we then have:

$$
\begin{aligned}
H = g\,&[(\bar{p}ON)(\bar{e}O\nu_1) + (\bar{N}Op)(\bar{\nu}_2O\mu) \\
&+ (\bar{\nu}_2O\mu)(\bar{e}O\nu_1) + \text{Herm. c.}] \\
&+ (g/2)\,[(eO\nu_1)(\bar{\nu}_1Oe) + (\bar{\mu}O\nu_2)(\bar{\nu}_2O\mu) - (\bar{e}Oe)(\bar{\nu}_2O\nu_2) \\
&- (\bar{\mu}O\mu)(\bar{\nu}_1O\nu_1) + (\bar{N}Op)(\bar{p}ON) + (\bar{e}Oe)(\bar{\mu}O\mu) \\
&+ (\bar{N}ON)(\bar{e}Oe) + (\bar{N}ON)(\bar{\mu}O\mu) - (\bar{p}Op)(\bar{e}Oe) \\
&- (\bar{p}Op)(\bar{\mu}O\mu) + (\bar{p}Op)(\bar{\nu}_1O\nu_1) + (\bar{p}Op)(\bar{\nu}_2O\nu_2) \\
&- (\bar{N}ON)(\bar{\nu}_1O\nu_1) - (\bar{N}ON)(\bar{\nu}_2O\nu_2) + (\bar{\nu}_1O\nu_1)(\bar{\nu}_2O\nu_2)] \\
&+ (g/4)\,[(\bar{e}Oe)(\bar{e}Oe) + (\bar{\mu}O\mu)(\bar{\mu}O\mu) + (\bar{p}Op)(\bar{p}Op) \\
&+ (\bar{N}ON)(\bar{N}ON) + (\bar{\nu}_1O\nu_1)(\bar{\nu}_1O\nu_1) + (\bar{\nu}_2O\nu_2)(\bar{\nu}_2O\nu_2)]. \quad (3)
\end{aligned}
$$

Unlike the expression (2), the Hamiltonian (3) contains no exceptions to the rule state above, and there is scattering of neutrinos by electrons and by μ mesons. By what do ν_1 and ν_2 differ? A theoretically permissible assumption is that they differ in the value of the chirality ($\gamma_5\nu_{1,2} = \pm\nu_{1,2}$) while having the same leptonic charge.* This assumption, however, leads to a contradiction with the experimental data on the spectrum of the electrons from μ decay (it gives the Michel parameter $\rho = 0$).

We shall show that the existing experimental data do not contradict the alternative theoretical hypothesis, namely that while having the same chirality ν_1 and ν_2 have different leptonic charges. In this case the leptonic charges will also be opposite for the electron and μ meson when the electric charges are the same.* The properties of the leptons are conveniently shown in a table.

Here I_Z is the isotopic spin projection, l is the leptonic charge, γ_5 is the chirality in the weak interactions,[5] e is the electric charge, and S is the "strangeness" calculated by the formula $e = I_Z + l/2 + S/2$. A particularly significant fact is that the data of this table, together with the requirements of conservation of electric charge, leptonic charge, and chirality, uniquely determine the character of the μ decay, $\mu^- \rightarrow e^- + \tilde{\nu}_1 + \nu_2$, and give rigorous selection rules that forbid various unobserved reactions involving leptons:*

	I_z	l	γ_5	e	S
e^-	−1/2	−1	+1	−1	0
ν_1	1/2	−1	+1	0	0
μ^-	−1/2	+1	+1	−1	−2
ν_2	1/2	+1	+1	0	−2
e^+	1/2	+1	−1	+1	0
$\tilde{\nu}_1$	−1/2	+1	−1	0	0
μ^+	1/2	−1	−1	+1	+2
$\tilde{\nu}_2$	−1/2	−1	−1	0	+2

$$
\begin{gathered}
\mu \rightarrow e + \gamma,\ \mu \rightarrow e + 2\nu,\ \mu \rightarrow e + e^+ + e^-, \\
K \rightarrow \pi + e^- + \mu^+,\ p + e \rightarrow p + \mu,\ \Lambda^0 \rightarrow n + \mu + e
\end{gathered}
$$

and so on. The reaction $n + \nu \rightarrow p + e$ is impossible with the neutrino produced in μ capture. Since leptons can occur in all the interactions only in the isotopic pairs ($\nu_1 e$) and ($\nu_2\mu$), it is impossible for the neutrinos produced in the μ decay of $\pi^\pm$ mesons ($\pi^\pm \rightarrow \mu^\pm \pm \nu_2$) to react with nucleons (or nuclei) to produce electrons; that is, the reactions $p + \tilde{\nu}_2 \rightarrow n + e^+$, $n + \nu_2 \rightarrow p + e^-$ are impossible.[6]† The fact that μ^+ mesons do not annihilate with atomic electrons finds a natural explanation.

If we start with our classification of leptons into isotopic doublets, the expression for the Hamiltonian of the four-fermion interactions involving only leptons and nucleons is uniquely determined in the form (1), on the basis of the requirements of Lorentz and isotopic invariance, conservation of chirality, conservation of the leptonic charge, and invariance of the interaction with respect to any interchanges of the type $l_1 \rightleftarrows l_2$, $l_{1,2} \rightleftarrows B$ (universality of the interaction).‡

In conclusion we point out the following. In a paper by Goldhaber[9] the hypothesis is suggested that fermions have a "doublet" character, and that

*The concept of leptonic charge was first introduced in a paper by Konopinski and Mahmoud.[7]

†The assumption that electrons and μ mesons of the same electric charge differ in their values of another ("neutrino") charge was suggested by Zel'dovich in 1953.[8]

*It is not hard to verify that all five of the reactions

$$\mu \rightarrow e + 2\nu_{1,2},\ \mu \rightarrow e + 2\tilde{\nu}_{1,2},\ \mu \rightarrow e + \nu_1 + \tilde{\nu}_2.$$

are forbidden.

†It is not hard to show that interactions between nucleons (or nuclei) and the neutrinos produced in the decay of slow π mesons cannot lead to the production of observable leptons (electrons or μ mesons).

‡For the choices of "particles" and "antiparticles," and also for the choice of the sign of the operator O, we appeal to experiment. The experimental value of the Michel parameter forces us to take simultaneously as "particles" ($\nu_1 e^-$) and ($\nu_2\mu^-$).[6] The left-hand screw neutrino in β decay corresponds to the sign "+" in the operator O.

"doublets" of the type $(e\mu)$ (the electron and μ meson were regarded as two states of the same particle) can also occur in the case of the heavy fermions. Accordingly, it was suggested that there be an experimental search for the heavier component of the proton doublet. From the point of view of the theory presented here, with two neutrinos, this question is obviously settled in the sense that the situation in the lepton case cannot be repeated, since it is due to the peculiarities of the neutrinos: in this sense the existence of the μ meson is a direct consequence of parity nonconservation.*

The writer is deeply grateful to Ya. B. Zel'dovich for his attention and interest in this work, to I. S. Shapiro and L. B. Okun' for discussion and criticism, and to V. A. Yakovlev for support.

*If we put in correspondence with the "ordinary" lepton doublet $(\nu_1 e)$ a nucleonic isotopic doublet $(\tilde{n}\tilde{p})$, then the analogue of the "strange" lepton doublet will be $(\Xi^0 \Xi^-)$.

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Translated by W. H. Furry
205