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A POSSIBLE TEST OF A TWO-COMPONENT THEORY OF THE NEUTRINO[*]

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Recently Lee and Yang have proposed a two-component theory of the neutrino.[1] In this theory, the violation of space-inversion invariance in processes involving the neutrino is easily understood. However, it seems to be useful to make clear the difference between the usual four-component theory of the neutrino and the new two-component theory. The purpose of this letter is to consider a possible test of this difference in μ-meson decay.

The neutrino field, ψ_ν , in the two-component theory appears in interactions in the combination $(1 \mp \gamma_5)\psi_\nu$, as shown by Lee and Yang. Therefore, in the process involving only one neutrino, all calculations using the two-component theory give the same results as the four-component theory with the Hamiltonian including such a term as $(\psi^* O_i(C_i + C'_i \gamma_5)\psi_\nu)$, if we take the special choice of $C_i = \mp C'_i$. The terms with either coefficients, C_i or C'_i, are parity-nonconserving interactions. But, if the process includes two or more neutrinos, the four-component theory gives some additional contributions that cannot be obtained by using the two-component theory. Therefore we may distinguish the four-component theory from the two-component theory. We will consider the μ-meson decay as an example.

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Let us consider only the process

$$\mu^{\pm} \rightarrow e^{\pm} + \nu + \bar{\nu} \quad . \tag{1}$$

The calculations are based on the interaction Hamiltonian density,

$$H_{int} = \sum_{i} (\psi_e^{+} O_i \psi_\mu)(\psi_\nu^{+} O'_i \psi_\nu) \quad , \tag{2}$$

where the notation is the same as that used by Lee and Yang,[1] except that O'_i means $f_i O_i$ in the two-component theory and $O_i(C_i + C'_i \gamma_5)$ in the four-component theory. In the two-component theory, the projection operator for the neutrino field includes the factor $(1 \mp \gamma_5)$. The operators O_i that involve an even number of γ_μ's commute with this $(1 \mp \gamma_5)$ factor. Therefore, as Lee and Yang have shown, only the V- and A-type couplings contribute to the electron-distribution function. At the same time, we can see easily that one must obtain the same result for the four-component theory as for the two-component theory if we choose the special cases of $C_V = \mp C'_V$ and $C_A = \mp C'_A$.

For μ meson at rest, with spin completely polarized, the electron distribution is given by

$$W(p, d\Omega_e) = \lambda \, dp \, d\Omega_e \left(\frac{1}{4\pi}\right) 2p^2 \left[\left\{ 6(1 - p) + \frac{4}{3} \rho (4p - 3) \right\} + \xi \cos\theta \, (1 - 2\gamma p) \right] , \tag{3}$$

where $\lambda = \eta \, p_o^5 / 6(2\pi)^3$, $(1/\lambda)$ is the lifetime of the μ meson, and p_o is the maximum electron momentum; p is the electron momentum in the unit of p_o, $d\Omega_e$ is the solid angle of electron momentum, and θ the angle between electron momentum and the spin direction of the μ.

The mass of the electron is neglected in this calculation ($\hbar = c = 1$). The other notations are given as follows:

In the two-component theory of the neutrino, we have

$$\eta = 2(|f_V|^2 + |f_A|^2), \qquad \rho = 3/4,$$

$$\eta\xi = 2ab(f_V^* f_A + f_A^* f_V), \qquad \delta = 1. \tag{4}$$

Here the a in $\eta\xi$ means the values of (± 1) corresponding to the special choice of neutrino field $(\psi_\nu = (1 \mp \gamma_5)\psi_\nu)$, and the b also means the values of (± 1) corresponding to the μ mesons in the positive and negative energy states, respectively.[2]

In the four-component theory of the neutrino, we have

$$\eta = (|F_S|^2 + 4|F_V|^2 + 6|F_T|^2 + 4|F_A|^2 + |F_P|^2),$$

$$\eta\rho = (3|F_V|^2 + 6|F_T|^2 + 3|F_A|^2),$$

$$\eta\xi = b(6F_S^* F_P - 4F_V^* F_A + \mathrm{C.C.}) - 4b(C_T^* C'_T + C'^*_T C_T),$$

$$\eta\xi\delta = b(3F_S^* F_P - 4F_V^* F_A + \mathrm{C.C.}) + 2b(C_T^* C'_T + C'^*_T C_T), \tag{5}$$

where

$$|F_i|^2 = |C_i|^2 + |C'_i|^2 \quad \text{and} \quad F_i^* F_j = (C_i^* C'_j + C'^*_i C_j).$$

For the special case of only the S- and P-type couplings, $\delta = +\frac{1}{2}$, and for the pure T-type coupling, $\delta = -\frac{1}{2}$.

It is clear from the above result that the Michel[3] parameter ρ and the other parameter γ must have the definite numerical values, 3/4 and 1, respectively, in either the two-component theory or for the mixture of the V- and T-type couplings in the four-component theory. The preliminary experimental result concerning electron distribution at the University of Chicago indicates $\gamma \simeq 1$.[4] This fact seems to support the two-component theory of the neutrino, as well as the recent measurement of Michel's ρ value.[5,6,7]

In the above, the result obtained by the special combination $(e\,,\mu)(\nu\,,\nu)$ of four leptons was described. Next let us consider the other combinations, for example, $(e,\nu)(\nu\,,\mu)$. Even with this choice of the interaction Hamiltonian density, the conclusion ($\rho = 3/4$ and $\gamma = 1$) in the two-component theory of the neutrino is not changed, although the S- and P-type couplings contribute to the distribution function of electrons. In addition, it is found--surprisingly--that ξ is always equal to $-ab(=\pm 1)$ for the combination of the V- and A-type couplings, and ξ is always equal to $(+ab)$ for the combination of the S- and P-type couplings; that is, the value of ξ does not depend on the order of magnitude of coupling constants, if we use the special combination of the (SP) or (VA) type couplings. This conclusion ($|\xi| = 1$) is also true for any pure-type coupling with this special choice of the Hamiltonian density, e.g., $\xi = -ab$ for the pure V-type coupling and $\xi = +ab$ for the pure S-type coupling. It is clear that, with this combination $(e,\nu)(\nu\,,\mu)$, we cannot obtain the simple relation between results obtained in the two- and four-component theories of the neutrino. The detailed result will be presented in a full report.

If the experimental result is $\xi = -1$, $\rho = 3/4$, and $\delta = 1$ for the positively charged μ meson, it is quite natural from the point of view of the universal Fermi interaction to assume the (STP) combination with the interaction Hamilton density of the $(e, \nu)(\nu', \mu)$ type in the two-component theory, $(a = +1)$, of the neutrino,[8] in which the negatively charged leptons (μ and e) are light particles $(b = +1)$.

1. T. D. Lee and C. N. Yang, Phys. Rev. (to be published), "Possible Parity Nonconservation and a Two-Component Theory of the Neutrino."

2. In the experiment, the general expression of the electron distribution is given by $(\alpha + \beta \cos \phi)$, in which α and β are functions depending on the energy of emitted electrons and ϕ is the angle between electron and μ-meson momenta. If the β has the same sign for both the positively and negatively charged μ mesons in the experiment, then the spin direction of the positively charged μ meson is opposite to the spin direction of the negatively charged μ meson. This relationship is easily understood in the two-component theory of the neutrino.

3. L. Michel, Proc. Phys. Soc. (London) A63, 514 (1950).

4. V. L. Telegdi; lecture at the Radiation Laboratory, University of California, on March 5, 1957.

5. Sargent, Rinehart, Lederman, and Rogers, Phys. Rev. 99, 885 (1955).

6. Crowe, Helm, and Tautfest, Phys. Rev. 99, 872 (1955).

7. Sagane, Dudziak, and Vedder, private communication (to be published in Phys. Rev.). Their experimental result is $\rho = 0.72 \pm 0.04$.

8. Wu, Ambler, Hayward, Hoppes, and Hudson, Phys. Rev. (to be published).