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NOTE ON LEPTONIC DECAY OF PION*

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Pion is known to decay into mu-meson and neutrino. The problem arises, however, of understanding the apparent non-occurence of an electron mode of decay for the pion. Experiments indicate that the ratio $R = \frac{\pi \to e + \nu}{\pi \to \mu + \nu}$ for the decay rates of the two modes is less than 10^{-5}. [1]

Recently, a Universal Vector - Axial Vector Fermi interaction has been proposed to explain the experiments in beta-decay and mu-decay.[2] In this theory, with the lepton pair inter-acting at the same point in space-time, the ratio of the two modes of decays is found to be 1.36×10^{-4}. [3] This ratio is larger by a factor of ten from the experimental observations and presents a serious difficulty for local V-A theory. We wish to show in this note that, in order to explain the discrepancy, it seems necessary to introduce in the above Fermi interaction a term which is essentially

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different in structure from that involved in V-A theory.

The matrix element for the decay of the pion into an electron (or mu-meson) of four-momenta p_e and a neutrino of four-momenta p_ν can be written, apart from phase space factors, as

$$S \simeq \overline{U}_e\ (p_e) \left[Q_o + Q_e \right] U_\nu\ (p_\nu)$$

where,

$$Q_o = \frac{\not{p}_e}{M} \left[1 + b\ \frac{p_e . p_\nu}{M^2} + c\ \frac{p_e^2}{M^2} \right]$$

and

$$Q_e = \left[a' + b'\ \frac{p_e . p_\nu}{M^2} + c'\ \frac{p_e^2}{M^2} \right]$$

Here we have used the following relations for neutrino

$$\not{p}_\nu\ U_\nu (p_\nu) = 0 \qquad p_\nu^2 = 0$$

M ($\gg m_{e,\mu}$) is some characteristic mass involved in the intermediate virtual process. b,b', a',b' and c' are constants to first order in four-momentum transfer involved in the decays.

The terms Q_o and Q_e are distinct in having odd and even number of gamma-matrices respectively. In "Two Component Theory"[4] with a left-handed [3] neutrino Q_o allows a left-handed electron while Q_e allows a right-handed electron in the extreme relativistic limit. In V-A theory the matrix element has only the term Q_o and the ratio of the decay modes can be written as

$$\frac{R}{R_o} = \frac{\left[1 + \frac{b}{2} \left(\frac{m_\pi}{M}\right)^2 - \left(\frac{b}{2} - c\right) \left(\frac{m_e}{M}\right)^2 \right]^2}{\left[1 + \frac{b}{2} \left(\frac{m_\pi}{M}\right)^2 - \left(\frac{b}{2} - c\right) \left(\frac{m_\mu}{M}\right)^2 \right]^2}$$

where

$$R_o = \frac{m_e^2\ (m_\pi^2 - m_e^2)^2}{m_\mu^2\ (m_\pi^2 - m_\mu^2)^2} = 1.36 \times 10^{-4}$$

Here we made use of energy momentum conservation. Thus, to obtain cancellation in the numerator while not affecting the denominator appreciably, we require the coefficient of $(\frac{m_e}{M})^2$ to be very large. This seems improbable in any perturbation calculation with V-A theory. However, if by small modification of the Fermi interaction we might allow small admixture of the term of the second type Q_e, then it is possible to decrease the electron mode appreciably compared to the muon mode. In fact the ratio in the general case is given by

$$\frac{R}{R_o} = \frac{\left[1 + \frac{b}{2} (\frac{m_\pi}{M})^2 - (\frac{b}{2} - c) (\frac{m_e}{M})^2 + a'(\frac{M}{m_e}) + \frac{b'}{2}(\frac{m_\pi^2}{Mm_e}) - (\frac{b'}{2} - c')(\frac{m_e}{M}) \right]^2}{\left[1 + \frac{b}{2} (\frac{m_\pi}{M})^2 - (\frac{b}{2} - c) (\frac{m_\mu}{M})^2 + a'(\frac{M}{m_\mu}) + \frac{b'}{2}(\frac{m_\pi^2}{Mm_\mu}) - (\frac{b'}{2} - c')(\frac{m_\mu}{M}) \right]^2}$$

With small coefficients a',b' and c' we can obtain cancellation for electron decay while the mu-mode is not appreciably affected.

Addition of a small Pseudo-scalar interaction to the V-A interaction does not seem to be consistent with electron spectrum in mu-decay, the ratio of electron mode and muon mode in pion decay and beta decay. Alternatively, we might introduce the other types of interaction terms (scalar, tensor and pseudo-scalar) in a non-local theory which involves derivatives in fermion fields. These terms will become important when large four-momentum-transfers are involved as in pion and K-meson decays. These terms will not affect appreciably the beta-decay where the four-momentum transfer involved is relatively small. The local V-A theory will then be exactly valid when the momentum transfer involved is zero[5].

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