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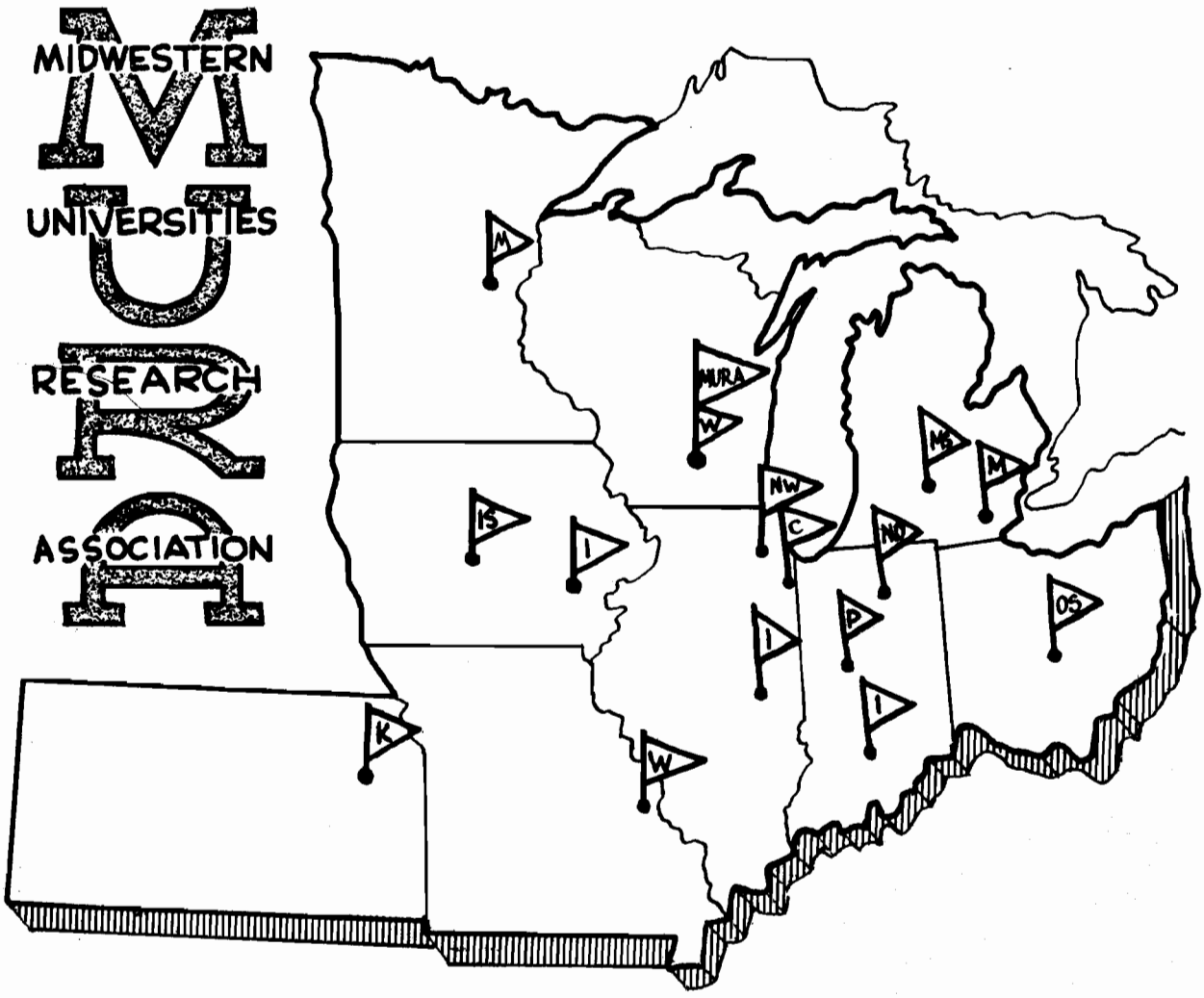

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S. P. Rosen

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ABSTRACT

The assumption that the neutrinos ν_1, ν_2 emitted in μ-capture and β-decay respectively have opposite helicity is shown not to be inconsistent with present experimental data. A crucial test of this assumption is the measurement of the helicity of muons emitted in $(\pi - \mu)$-decay.

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Lee and Yang have recently drawn attention to the possibility that the neutrinos ν_1, ν_2, emitted in μ^--capture and β^+-decay respectively

$$\begin{aligned} \mu^- + p &\rightarrow n + \nu_1 \\ (A,Z) &\rightarrow (A,Z-1) + e^+ + \nu_2 \end{aligned} \tag{1}$$

may not be identical particles.[1] Indeed, if the absence of the photo-decay $\mu \rightarrow e + \gamma$ is to be reconciled with the Intermediate Vector Boson Theory[2] of weak interactions, then it must be assumed that:

(a) the helicity of ν_1 is the same as the helicity of ν_2

(b) ν_1 and ν_2 must differ in some internal coordinate which may, perhaps, be the analogue for leptons of the "strangeness" of hyperons and K-mesons.

After the discussion by Lee and Yang had appeared, it was reported that an attempt to measure the helicity of the μ^- emitted in π^--decay had yielded no definite result.[3] Therefore, since the helicity of ν_1 is still an open question, it is of some interest to examine the consequences of an assumption alternative to (a), namely

(a') ν_1 and ν_2 are created with opposite helicities in μ^--capture and β^+-decay respectively.

Let us suppose that the coupling of leptons to bare nucleons is V-A, both for β-decay and μ-capture.[4] Since the helicity of ν_2 in (1) is negative,[5] the interaction Hamiltonian is

$$\begin{aligned} \mathcal{H}_\pm = (\bar{\psi}_p \gamma_\lambda (g_V + g_A \gamma_5) \psi_n) \Big[(\bar{\psi}_\mu \gamma_\lambda (1 \pm \gamma_5) \psi_{\nu_1}) \\ + (\bar{\psi}_e \gamma_\lambda (1 + \gamma_5) \psi_{\nu_2}) \Big] + h.c. \end{aligned} \tag{2}$$

where the positive sign corresponds to assumption (a) and the negative

to (a'). From the conservation of spin and momentum in π-decay,

$$\pi^- \begin{array}{l} \nearrow \mu^- + \bar{\nu}_1 \\ \searrow e^- + \bar{\nu}_2 \end{array} \tag{3}$$

(for clarity we shall only consider the π^-) it follows that $\mathcal{H}_-$ implies the same branching ratio of the ($\pi - e$) mode to the ($\pi - \mu$) mode as does $\mathcal{H}_+$; this theoretical ratio is in agreement with the experimental value.

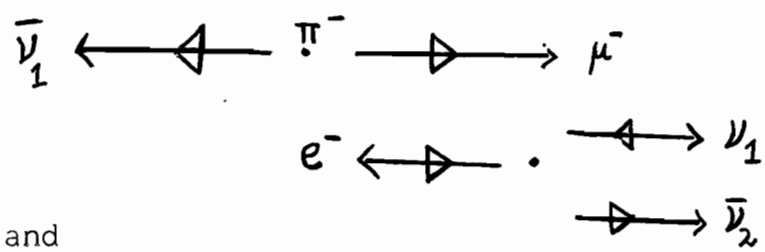
Consider now the $\pi - \mu - e$ chain: the only established experimental facts are:[5]

(i) the electrons $e^{\pm}$ are emitted predominantly anti-parallel to the $\mu^{\pm}$ momentum,

(ii) the helicity of $e^{\pm}$ is ± 1 (the electron mass is neglected),

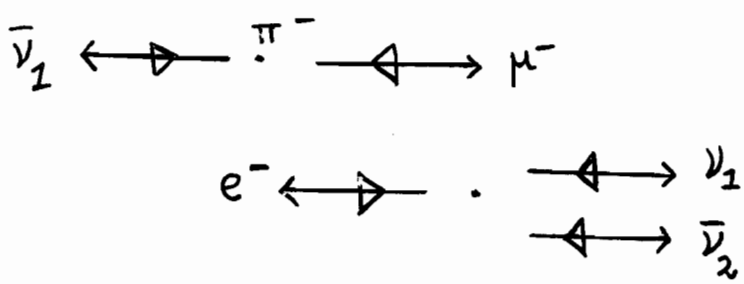
(iii) the measured values of the Michel parameters in μ-decay are $\rho \approx 0.75$, $\delta \approx 0.6$, $|\xi| \approx 0.8 - 1.0$.

When the electron has its maximum momentum, the helicity assignments consistent with (i), (ii) and the conservation of spin and momentum are



for $\mathcal{H}_+$ (4)

and



for $\mathcal{H}_-$ (5)

(The designation of the neutrinos in μ-decay will be discussed later). The configuration in (4) leads to the usual V, A Hamiltonian for μ-decay, while that in (5) leads to S,T,P coupling:

$$\mathcal{H}_-(\mu \to e + \nu_1 + \bar{\nu}_2) = \sum_{i=S,T,P} g_i \left(\bar{\psi}_e \Gamma_i (1-\gamma_5)\psi_\mu\right)\left(\bar{\psi}_{\nu_1} \Gamma_i (1-\gamma_5)\psi_{\nu_2}\right) + h.c. \tag{6}$$

$$\Gamma_S = 1 \quad , \quad \Gamma_P = \gamma_5 \quad , \quad \Gamma_T = \frac{i}{2\sqrt{2}}\left(\gamma_\mu \gamma_\nu - \gamma_\nu \gamma_\mu\right)$$

The electron spectrum obtained from $\mathcal{H}_-(\mu \to e + \nu_1 + \bar{\nu}_2)$ is

$$dN_-(x,\theta) \sim \left\{3(1-x) + 2\rho\left(\tfrac{4}{3}x - 1\right) + \xi \cos\theta\left[1 - x + 2\delta\left(\tfrac{4}{3}x - 1\right)\right]\right\} x^2 dx\, d\Omega \tag{7}$$

where

$x \equiv$ (electron energy/maximum electron energy)

$\theta \equiv$ angle between electron momentum and muon spin direction

$$\rho = 12|g_T|^2 / \left(|g_S + g_P|^2 + 12|g_T|^2\right)$$

$$\xi = \left(28|g_T|^2 - 3|g_S + g_P|^2\right) / \left(|g_S + g_P|^2 + 12|g_T|^2\right)$$

$$\delta = \rho / \xi$$

When $g_S = g_P = \pm g_T$

$$\rho = \delta = 3/4 \quad , \quad \xi = 1 \tag{8}$$

which values are consistent with the data in (iii).[6]

It is assumed that the neutrinos emitted in μ-decay are ν_1 and $\bar{\nu}_2$ in order to conserve lepton charge and any other such quantum number as may be associated with leptons (see assumption (b)). The assumption (a') clearly implies that ν_1 and ν_2 are both four-component neutrinos since their respective helicities in μ-decay (see (5)) are opposite from those in β-decay and μ-capture. While it does not matter, in (4), whether ν_1 and $\bar{\nu}_2$ are identical particles, the Pauli Principle requires that they be distinct in configuration (5), i.e.,

$$\nu_1 \not\equiv \bar{\nu}_2 \tag{9}$$

It is now clear that the immediate consequences of assumption (a') must be the rejection of (i) the universality of V - A coupling in weak interactions, (ii) the "two-component" neutrino, and (iii) the Intermediate Vector Boson Theory, at least in its present form. A further consequence is that the neutrino-capture reaction

$$\pi^+ \rightarrow \mu^+ + \nu_1 \quad , \quad \nu_1 + n \rightarrow p + e^- \tag{1}$$

and the second-order process[7]

$$\mu^- + p \longrightarrow n + \nu_1 \rightarrow e^- + p \tag{11}$$

do not occur, whether ν_1 is identical to ν_2 (which would be allowed by (9) if ν_2 is a Dirac particle), or not; for, according to $\mathcal{H}_-$ (see (2)). the helicity of ν_1 is opposite to that required for absorption by a neutron together with the simultaneous emission of an electron.

The validity of (a') depends, of course, upon the helicity of the muon emitted in ($\pi - \mu$)-decay. We should like to draw attention to the consequences described above, in order to encourage attempts at this difficult experiment.

The author would like to thank W. Holladay, M. E. Ebel and M. H. Good for their encouragement and helpful comments.

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2. We take the Intermediate Vector Boson Theory to imply that all weak interactions are generated by the coupling of the vector boson to a current; see for example M. Gell-Mann, Rev. Mod. Phys. 31 834 (1959).

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6. Starting from a somewhat different point of view, L. B. Okun and V. M. Shekhter (Soviet Phys. JETP 34, 1250 (1958) obtain the same results as in this paragraph. The author is indebted to Prof. R. G. Sachs for this reference.

7. If the intermediate boson does not exist, (11) is the only possible mechanism for the decay $\mu + p \rightarrow e + p$: see S. P. Rosen, Nuovo Cimento 15, 7 (1960).