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A MODEL OF THE UNIVERSAL FERMI INTERACTION

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ABSTRACT

It follows from the Feynman-Gell-Mann theory that the Fermi interaction can be regarded as due to an exchange of charged vector mesons between fermions. An alternative model is possible: the weak couplings among fermions may be due to an exchange of charged and neutral vector mesons. An extra condition of conservation of the current which creates the neutral field is imposed to forbid unobserved reactions. The model differs from the Feynman-Gell-Mann picture in that it leads to an intrinsic electron-neutron interaction, the effective potential being of the order of 4 ev. If the coupling of this hypothetical vector meson with fermions has the

same strength as the electric charge, the particle will have about 60 proton masses and will decay very fast into pairs of hyperons.

The hypothesis of a universal Fermi interaction must be formulated in such a way as to predict a sufficiently small or vanishing transition rate for fermion decays which have not been observed experimentally.

It is usual to say that the coupling acts between given pairs of fermions: (e^+,ν) with (μ^+,ν) and with $(p,\bar{n})$, $(\Sigma^+,\bar{\Lambda})$, $(\Sigma^+,\bar{\Sigma}_0)$, (Ξ^-,Ξ_0).[1] This association excludes couplings of (μ^+,e) with (e^+,e) or $(\bar{p},p)$ which would give rise to the non-observed reactions.

$$\begin{aligned} &\mu^+ \rightarrow e^+ + e^+ + e \\ &\mu^- + p \rightarrow p + e \end{aligned} \qquad 1)$$

However, in the decay of muons:

$$\mu^+ \rightarrow e^+ + \nu + \bar{\nu}$$

the experimental data are consistent with the vector-axial vector coupling of (μ^+,ν) with $(\bar{\nu},e)$ which is equivalent to the same coupling of (μ^+,e) with $(\bar{\nu},\nu)$. If the latter is regarded as physically possible one does not see the reason to forbid the couplings which would give rise to reactions (1) in first order.

Feynman and Gell-Mann[2] have proposed a vector-axial vector coupling theory for the Fermi interaction which is in agreement with most of the data on the reactions involving fermions only. As they pointed out, this coupling may be regarded as due to a virtual exchange of charged heavy vector mesons between two fermions. The relation between the mass of this hypothetical meson m_x, the coupling constant f_x of this meson x with the fermi field and the Fermi coupling constant G is:

$$4\pi \frac{f_x^2}{m_x^2} = \sqrt{8} \quad G \qquad 2)$$

The ordering of the fermion pairs in the Fermi couplings will now be well defined if we take this model seriously and postulate that <u>the weak interaction between two fermions is due to the virtual exchange of charged vector mesons</u>. It then becomes clear that reactions where there can be no charge exchange will be forbidden in first order in G. Thus the reactions (1) [3] can only occur as a result of the successive exchange of two charged vector mesons and are therefore less probable than the first order processes $\mu^{+} \longrightarrow e^{+} + \nu + \bar{\nu}$ and $\mu^{-} + p \longrightarrow n + \nu$, respectively, by a factor of order 10^{12}.

A consequence of this postulate is that the scattering of neutrinos by electrons is possible in first order as well as the neutron-proton scattering due to a weak, non-parity conserving interaction. <u>The Fermi scattering of neutrons by electrons is, however, forbidden in first order</u>: the electron can only emit negative vector mesons which the neutron cannot accept.[4]

We wish to point out that there is an alternative picture which describes the observed reactions, forbids the undesirable fermion decays and leads to some consequences which are different from those mentioned above and can be tested in principle. The model is the following: <u>assume that any two fermions can exchange charged and neutral vector mesons</u>. Assume, further, that the neutral vector meson enters the coupling with the fermi field in such a way that <u>the current which creates the neutral field is conserved</u> (the interaction is, then, not charge-independent). Reactions like those in (1), which have in a vertex one neutral vector meson line and two fermion lines corresponding to different fermion masses violate this condition and are therefore forbidden. This also excludes the coupling of (μ^+, e) with $(\bar{\nu}, \nu)$ and prescribes the unique interaction of (μ^+, ν) with $(\bar{\nu}, e)$ for the μ-e decay. In the scattering of neutrinos by electrons, the interaction is now of the form

$$G\left\{(\bar{e}\gamma_\mu a\nu)(\bar{\nu}\gamma_\mu a e) + (\bar{\nu}\gamma_\mu \nu)(\bar{e}\gamma_\mu e)\right. \quad , \quad a = \frac{1}{2}(1+i\gamma_5) \ .$$

Conservation of the fermion current which emits neutral mesons imposes that the second term must conserve parity. Thus, if this model is true, <u>only the weak interactions which involve charge exchange violate parity conservation</u>; there exist weak interactions, those involving an exchange of neutral vector mesons, which conserve parity.

An essential difference between this model and that which assumes the existence of only charged vector mesons is in the intrinsic electron-neutron interaction: the former leads to a scattering of neutrons by electrons due to a weak, non-electromagnetic, parity conserving coupling. If the corresponding effective potential is represented by a well of depth V and radius $e^2/(m_e c^2)$, the value of V is of the order of 4 ev, if we take the value 1.4×10^{-49} erg. cm^3 for the Fermi coupling constant G. A Fermi-type coupling between electrons and neutrons has already been suggested by Foldy[5]. It follows from our model of the universal Fermi interaction whereas it is practically non-existent in the Feynman-Gell-Mann picture. The scheme suggested here depends crucially on the vector-axial vector nature of the Fermi coupling. Only for neutral vector mesons can the extra condition be imposed to rule out the unobserved reactions.

The hypothetical vector meson would be a very heavy and unstable particle. Its lifetime is:

$$\tau_x \approx \frac{16\pi}{f_x^2/(\hbar c)} \; \frac{\hbar}{m_x c^2}$$

for a decay into a nucleon (or hyperon) pair ($m_p/_{m_x} \ll 1$). Taking (2) into account and $G \approx 10^{-5} \frac{\hbar^3}{m_p^2 c}$ we have

$$\tau_x \approx \frac{10^{-17}}{x^3} \text{ sec}, \quad x = {}^{m}x/m_p$$

and

$$f_x^2 \,/\, (\hbar c) = 2{,}2 \cdot 10^{-6}\, x^2 \, .$$

If we set $f_x^2 = e^2$, one obtains $m_x \approx 60\, m_p$ and $\tau_x \approx 10^{-22}$ sec.

The author had stimulating conversations with C. M. G. Lattes, J. Tiomno, L. Marquez and P. Srivastava.

1. See for example, J. Leite Lopes, An. Acad. Brasil. Ci. 29 (1957), 521.

2. R. P. Feynman and M. Gell-Mann, Phys. Rev. 109 (1958) 193; also E. C. G. Sudarshan and R. E. Marshak, Padua-Venice International Conference on "Mesons and Recently Discovered Particles" - September 22-28, 1957.

3. Direct radiative decays like $\mu^+ \rightarrow e^+ + \gamma$ and $\Sigma^+ \rightarrow p + \gamma$ cannot obviously occur by vector coupling with the electromagnetic field due to gauge invariance with respect to the latter. An effective tensor interaction with $F_{\mu\nu}$ is possible and results from the muon changing into an intermediate neutrino with the creation of a proton-antineutron closed loop which emits the γ-ray and annihilates the neutrino into the final electron. The rate is, however, of order G^2 and thus undetectable. If the radiative decay of Σ^+ proceeds via an intermediate pion and proton the lifetime is of order 10^{-3} sec.

4. We assume the principle of baryon number conservation. In first order in G,

the exchange of vector mesons between e and n may lead to the reaction $e + n \rightarrow \Sigma^- + \nu$ for which one needs neutrons with energy higher than about 260 Mev. In second order, one may have the e - n scattering $e + n \rightarrow \Sigma^- + \nu \rightarrow e + n$ which, however, gives no detectable contribution to the scattering cross section.