PRESENT EXPERIMENTAL EVIDENCE FOR A FERMI INTERACTION IN MUON CAPTURE*

Valentine L. Telegdi
The Enrico Fermi Institute for Nuclear Studies, University of Chicago, Chicago, Illinois
(Received March 6, 1962)

Today there is firm experimental evidence that the 4-fermion couplings $(np)(e\nu)$ and $(\mu e)(e\nu)$ are of the "$V-xA$" type. The strength of this evidence stems from the fact that it is largely based on measured features of the relevant fundamental decay processes (free n, μ^+).

Considerably less is known about the nature of the $(np)(\mu\nu)$ coupling, although all experimental evidence is consistent with the assumption that it also is (predominantly) of the "$V-xA$" type. This ignorance is due to the lack of data on the fundamental reaction $p+\mu\to n+\nu$, for which a first experimental rate estimate has just been published.[1] One has a wealth of rather precise data on muon capture by complex nuclei, but there has been occasional doubt as to their usefulness for deriving quantitative conclusions about the detailed nature of the $(np)(\mu\nu)$ coupling. In fact it has been argued[2] recently that all these data are consistent with a pure Gamow-Teller (GT, presumably A) interaction.

The purpose of this note is to point out that the data on complex nuclei can be used to provide fair evidence for the simultaneous presence of both GT and F (Fermi, presumably V) interactions in muon capture with roughly the strength predicted from the hypothesis of universality.

The argument is based on a comparison of Primakoff's well-known closure calculation[3] result for the spin-averaged capture rate, $\bar{\Lambda}(Z,A)$, of a nuclide of charge Z, mass number A:

$$\bar{\Lambda}(Z,A)/Z_{\text{eff}}^4=\bar{\Lambda}(1,1)\gamma[1-(A-Z)\delta/2A], \tag{1}$$

where

$$\gamma=\langle\eta\rangle_{Z,A}^2/\eta_{1,1}^2,\quad \eta_{1,1}^2=0.58,$$

with experiment. Such a comparison has already been made by Primakoff himself and elsewhere,[4] and we merely give here a graphic argument that emphasizes the presence of a Fermi interaction.

In Eq. (1), atomic properties are reflected in the reliably calculable factor Z_{eff}^4, nuclear properties in the parameters $\langle\eta\rangle^2$ and δ, and the nature of the weak interaction in the spin-averaged "proton" capture rate $\bar{\Lambda}(1,1)$:

$$\bar{\Lambda}(1,1)\sim(G_V^2+3\Gamma_A^2),$$

$$\Gamma_A^2=G_A^2+(\tfrac{1}{3})(G_P^2-2G_PG_A), \tag{2}$$

with G_A, G_V, and G_P coupling constants in an effective nonrelativistic Hamiltonian; these are functions of the muon "dressed" coupling constants $g_A^{(\mu)}$, $g_V^{(\mu)}$, $g_P^{(\mu)}$ in the relativistic interaction.[3]

Figure 1 shows a plot, for elements with $Z>8$, of the currently accepted values of $\bar{\Lambda}(Z,A)/Z_{\text{eff}}^4$

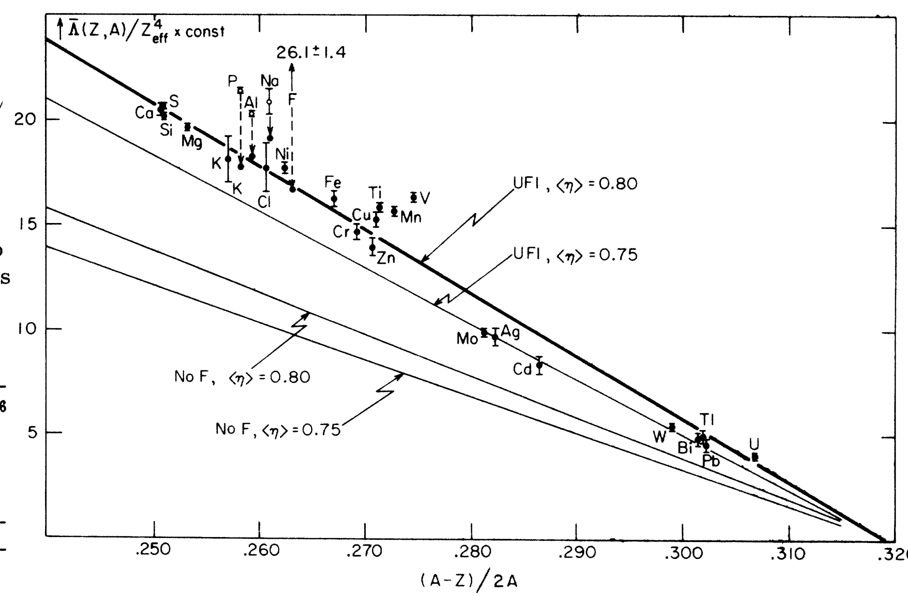

FIG. 1. Experimental values of $\bar{\Lambda}(Z,A)/Z_{\text{eff}}^4$ vs $(A-Z)/2A$. Ordinate is actually $\pi a_0^3\bar{\Lambda}(Z,A)/Z_{\text{eff}}^4$ in units of 10^{-31} cm^3 sec^{-1}, as in reference 4. Heavy line through experimental points is best fit with $\delta=3.13$, $\gamma\bar{\Lambda}(1,1)=183$ sec^{-1}, i.e., corresponds to UFI with $\langle\eta\rangle=0.80$. Open circles represent experimental points not used in fit because they are affected by hyperfine effects; downward arrows represent estimated corrections (experimental[6] for F^{19}, theoretical[5] for others) for this spin dependence. All lines in the figure correspond to $\delta=3.13$, but to different assumptions about $\langle\eta\rangle$ and $\bar{\Lambda}(1,1)$, as indicated.

vs the "fractional neutron excess" $(A-Z)/2A$. It is in the main an up-to-date version of Fig. 7 of reference 4. A best fit to the data indicated by solid circles yields

$$\text{Experiment: } \delta = 3.13, \quad \gamma\bar{\Lambda}(1,1) = 183 \text{ sec}^{-1}. \qquad (3)$$

A universal "$V - xA$" interaction, UFI [with $x = g_A^{(\beta)}/g_V^{(\beta)} = -1.21$, conserved V current, weak magnetism, induced P interaction, etc.[3]] leads to

$$\text{Theory, UFI: } \bar{\Lambda}(1,1) = 169 \text{ sec}^{-1}. \qquad (4)$$

The observed value of δ agrees well with Primakoff's estimate $\delta = 3$, and the general dependence of the reduced capture rates on $(A-Z)/2A$ approximates well the linear behavior implied by (1). With $\langle\eta\rangle = 0.8$, experiment and UFI prediction are in perfect agreement. Inasmuch as neither δ nor $\langle\eta\rangle$ are constants of nature, but rather reasonable mean values valid through the range of nuclides investigated, the scatter of the points about the best fit (heavy) line in Fig. 1 appears reasonable. The UFI prediction for $\langle\eta\rangle = 0.75$ is indicated for illustrative purposes. It is of interest to note that the $I \neq 0$ elements which were not included in making the fit (open circles) are brought down towards the best fit line if allowance is made for the hyperfine effect.[5,6] No obvious explanation is available for the group near Mn.

Let us compare experiment with the hypothesis that there is no Fermi (F) interaction in the muon capture interaction [$g_V^{(\mu)} = 0$, but $g_A^{(\mu)}$ and $g_P^{(\mu)}$ retained as before]. This corresponds to

$$\text{No-F theory: } \bar{\Lambda}(1,1) = 112 \text{ sec}^{-1}. \qquad (5)$$

This hypothesis disagrees with experiment quite markedly, as shown in Fig. 1, for either $\langle\eta\rangle = 0.80$ or $\langle\eta\rangle = 0.75$. One could argue that an agreement could be brought about by either (a) assuming that the GT coupling (A) is stronger in muon capture than in beta decay, or (b) assuming $\langle\eta\rangle \simeq 1$. Both of these assumptions are, however, in contrast with known experimental facts. The measured[7] capture rate from C^{12} to the ground state of B^{12} agrees with UFI for the GT and P couplings,[3] as does the μ-e branching ratio in pion decay. Measurements of neutron multiplicities in muon capture imply mean excitations[8] of at least 15 Mev, corresponding to $\langle\eta\rangle \leq 0.84$. Primakoff's *a priori* estimate of $\langle\eta\rangle$, presumably based on this source, was 0.75.

In conclusion, we believe that the capture data on complex nuclei are *not* compatible with the absence of an F interaction. The idea that they are, might have arisen from a fallacious analogy with the theory of beta decay. The decay rate of the free neutron, say, is of the form (2), with $G_V = g_V^{(\beta)}$ and $\Gamma_A = x g_V^{(\beta)}$, and the omission of the V coupling leads, with $x = -1.21$, only to a decrease by 20% of the predicted rate. For muon capture, however, the complicated dependence of Γ_A on the relativistic coupling constants leads to the surprising decrease implied by Eqs. (4) and (5).

Once our point of view is granted, the hyperfine effect in the capture of muons by[6] $_9F^{19}$ provides unambiguous evidence for UFI rather than for mere spin dependence.

Is is a pleasure to acknowledge the assistance of W. A. Cramer and R. Winston in the preparation of Fig. 1.

---

*Research supported by a joint program of the Office of Naval Research and the Atomic Energy Commission.

[1] R. H. Hildebrand, Phys. Rev. Letters 8, 34 (1962).

[2] L. Wolfenstein, Bull. Am. Phys. Soc. 7, 58 (1962).

[3] H. Primakoff, Revs. Modern Phys. 31, 802 (1959).

[4] J. C. Sens, Phys. Rev. 113, 679 (1959).

[5] J. Bernstein, T. D. Lee, C. N. Yang, and H. Primakoff, Phys. Rev. 111, 313 (1958).

[6] G. Culligan, J. F. Lathrop, V. L. Telegdi, R. Winston, and R. A. Lundy, Phys. Rev. Letters 7, 458 (1961).

[7] For the most recent, and presumably most accurate, determination see E. J. Maier, B. L. Bloch, R. M. Edelstein, and R. T. Siegel, Phys. Rev. Letters 6, 417 (1961).

[8] R. D. Sard and M. F. Crouch, *Progress in Cosmic-Ray Physics*, edited by J. G. Wilson (North-Holland Publishing Company, Amsterdam, 1954), Vol. 2.