[16] Consulting for example a list of matrix elements for AF, Eq. (2) of reference 3.
[17] C. N. Yang, Phys. Rev. **77**, 242 (1950).
[18] In expression (1) one could just as well replace $\cos\psi$ by P_p (the usual number denoting degree and sense of longitudinal particle polarization) and likewise $\cos\phi\sin\psi$ by P_ϕ (similarly standing for transverse polarization at azimuth ϕ). So long as $P_p^2+P_\phi^2$ is less than unity we have no absurdity.
[19] At very low energies ($\sim$10 kev), this term is the only link between P_p and P_k and its effect becomes isotropic to the extent that $(v/c)^2$ is neglected.
[20] That is, it could be canceled out more surely than the other $\cos\psi$ term. In fact, this "$J=0$" term in ϵ, at suitable energy, might even serve as a monitor of P_p to insure that the photon analyzer was active: data at ϕ and $\phi+180°$ could be added.
[21] Allowing use of low-Z and nonmagnetic annihilating substances.
[22] However, if one insisted *further* that the conjugate photon have opposite helicity to the photon at θ, ϕ, there is a little algebraic change: the new conversion efficiency is expression (1) modified by deleting the third ($J=0$) term in the numerator and also deleting the $1-\beta^4$ in the denominator. Notice that this new ϵ would apply only for completely efficient polarization analyzers, whereas the original expression (1) is valid independent of analyzer efficiency.

Universal Fermi Interaction*

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RECENT experimental evidence[1] seems to indicate that the Fermi coupling for beta decay may be of the form $V-A$, which in form and strength is also consistent with the muon decay data.[2] Also recently, several theoretical arguments[3–5] have been proposed for a universal Fermi interaction of the $V-A$ type. It is the purpose of this note to propose another theoretical argument for such a universal coupling.

In addition to the usual assumptions about the decay Hamiltonian regarding Hermiticity, quadrilinearity of the fermion fields, etc., the following assumptions are made.[6]

(i) The interaction Hamiltonian has the same form and coupling strength for any four fermions and for any order in which these four particles are written (subject to the conservation of charge, baryons, and leptons).

(ii) Lepton fields anticommute; baryon fields anticommute; a lepton field and a baryon field either commute or anticommute.[7]

(iii) The neutrino mass is identically zero, and hence the Hamiltonian is invariant under the substitution $\psi_\nu\rightarrow\pm\gamma_5\psi_\nu$.[8]

Assumption (i) is a statement of the universal Fermi interaction, and following Finkelstein and Kaus,[6] may be displayed explicitly by writing the interaction Hamiltonian as

$$F=\sum_{\sigma=0}^{4}\frac{1}{\sigma!}g_\sigma\sum_{abcd}(\bar\psi_a\Gamma^\sigma\psi_b)(\bar\psi_c\Gamma^\sigma\psi_d)+\sum_{\sigma=0}^{4}\frac{1}{\sigma!}g_\sigma'\sum_{abcd}(\bar\psi_a\Gamma^\sigma\psi_b)(\bar\psi_c\Gamma^\sigma\gamma_5\psi_d)+\text{H.c.},\quad(1)$$

where the Γ^σ are the completely antisymmetric Hermitian product of σ Dirac matrices, the g_σ are, in general, complex, and the indices a, b, c, and d refer to the four fermions which are interacting. The field operators, ψ_i, annihilate particles only (in the positive or negative energy state) while the $\bar\psi_i$ create particles only (this guarantees conservation of fermions). The conservation laws [see (i)] restrict the sum over *abcd*. It should be noted that the Γ^σ and g_σ are independent of this sum.

As an example, consider one process. Assume that the proton, neutron, electron, and neutrino are all particles. Then the terms in the sum over *abcd* in (1) which involve these four particles are (suppressing the matrices and allowing the symbol for a particle to denote a ψ_i),

$$(\bar pn)(\bar e\nu)+(\bar p\nu)(\bar en)+(\bar e\nu)(\bar pn)+(\bar en)(\bar p\nu)+(\bar np)(\bar\nu e)+(\bar ne)(\bar\nu p)+(\bar\nu e)(\bar np)+(\bar\nu p)(\bar ne)+\text{H.c.}\quad(2)$$

The first four terms correspond to neutron decay, the last four terms to proton decay.

If the Hermitian conjugate terms are now explicitly combined with the first two terms, (1) may be rewritten

$$F=\sum_{\sigma=0}^{4}\frac{1}{\sigma!}2\,\text{Re}(g_\sigma)\sum_{abcd}(\bar\psi_a\Gamma^\sigma\psi_b)(\bar\psi_c\Gamma^\sigma\psi_d)+\sum_{\sigma=0}^{4}\frac{1}{\sigma!}[g_\sigma'+(-)^{\sigma+1}g_\sigma'^*]\times\sum_{abcd}(\bar\psi_a\Gamma^\sigma\psi_b)(\bar\psi_c\Gamma^\sigma\gamma_5\psi_d).\quad(3)$$

Since the g_σ in (1) are complex, (1) contained twenty arbitrary constants. In (3) there are ten arbitrary constants.

From (2), it is apparent that the terms in the sum over *abcd* can be grouped according to the process, e.g., neutron decay, proton decay, etc. It is then possible, due to a theorem of Fierz,[9] to rewrite all the terms representing one process in terms of one ordering of the particles [e.g., in (2) the first four terms may be rewritten in terms of the first term]. The theorem is easily generalized to the pseudo-invariants.[10] If the commutation relations (ii) are observed, then for *each* process, F assumes the form[10]

$$F=h_1(S-T+P)+h_2(V-A)+h_3(S-A-P)+ih_4(S'-T'+P')+h_5(V'-A'),\quad(4)$$

where S, T, etc., correspond to the invariants $(\bar{\psi}_a\Gamma^\sigma\psi_b)\times(\bar{\psi}_c\Gamma^\sigma\psi_d)$ written in one ordering of particles, while S', T', etc., correspond to the pseudo-invariants. The constants, h_i, are all real and are independent of the process. The number of arbitrary constants is thus reduced to five.

According to assumption (iii), the Hamiltonian (1) must be invariant under the transformation $\psi_\nu \rightarrow \pm\gamma_5\psi_\nu$ whenever a neutrino process is considered. For a process involving a neutrino, (4) is invariant under this transformation only if $h_1=h_3=h_4=0$ and $h_2=\pm h_5$. But the constants in (4) are independent of the process. Therefore, for every process F has the form

$$F=h[(V-A)\pm(V'-A')].$$

The experimentally measurable quantities arising from this coupling have been discussed previously.[3–5]

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[1] Goldhaber, Grodzins, and Sunyar, Phys. Rev. **109**, 1015 (1958).
[2] See, for example, T. D. Lee and C. N. Yang, Phys. Rev. **105**, 1671 (1957).
[3] R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 193 (1958).
[4] E. C. G. Sudarshan and R. E. Marshak, *Proceedings of the Padua-Venice Conference on Mesons and Newly Discovered Particles, September, 1957* (to be published).
[5] J. J. Sakurai, Bull. Am. Phys. Soc. Ser. II, **3**, 10 (1958).
[6] Assumption (i) in the form (1) (for parity conservation) was proposed by R. Finkelstein and P. Kaus, Phys. Rev. **92**, 1316 (1953). Instead of (ii), they made the slightly less general assumption that all the fermion fields anticommute. Compare also D. L. Pursey, Phil. Mag. **42**, 1193 (1951), and Physica **18**, 1017 (1952); and E. R. Caianiello, Nuovo cimento **10**, 43 (1953).
[7] T. Kinoshita, Phys. Rev. **96**, 199 (1954).
[8] See, for example, A. Salam, Nuovo cimento **5**, 299 (1957).
[9] M. Fierz, Z. Physik **104**, 553 (1937).
[10] R. J. Finkelstein, Phys. Rev. **109**, 1842 (1958).

Errata

Plasma Oscillations in a Steady Magnetic Field: Circularly Polarized Electromagnetic Modes, TRILOCHAN PRADHAN [Phys. Rev. **107**, 1222 (1957)]. Equations (4) and (7) are printed erroneously. They should read:

$$\frac{\partial f_1}{\partial t}+\mathbf{u}\cdot\nabla_r f_1-\frac{e}{mc}(\mathbf{u}\times\mathbf{B})\cdot\nabla_u f_1=\frac{e}{m}\left(\mathbf{E}+\frac{\mathbf{u}}{c}\times\mathbf{B}\right)\cdot\nabla_u f_0, \quad (4)$$

$$\frac{\partial f_1}{\partial t}+\mathbf{u}\cdot\nabla_r f_1-\frac{e}{mc}(\mathbf{u}\times\mathbf{B})\cdot\nabla_u f_1-\frac{e}{mc}(\mathbf{u}\times\mathbf{B})\cdot\nabla_u f_1=\frac{e}{m}\mathbf{E}\cdot\nabla_u f_0. \quad (7)$$

High Negative Nuclear Polarizations in a Liquid, LAWRENCE H. BENNETT AND H. C. TORREY [Phys. Rev. **108**, 499 (1957)]. Equation (1) was printed incorrectly and should read:

$$\frac{A}{A_0}=1-\frac{1}{2}\frac{|\gamma_e|}{\gamma_n}\frac{s}{1+s}. \quad (1)$$

Magnetic Properties of UMn_2, S. T. LIN AND A. R. KAUFMANN [Phys. Rev. **108**, 1171 (1957)]. The first sentence of Sec. IVB should read: "The susceptibility, χ, at each temperature was obtained by applying the simple formula $\chi=\sigma/H$ to the corresponding isotherms at high fields and taking the mean values, and the data····."

Effect of Impurity Scattering on the Magnetoresistance of n-Type Germanium, MAURICE GLICKSMAN [Phys. Rev. **108**, 264 (1957)]. The values of magnetoresistance reported for crystal 1336 are in error due to a mistake in orientation. The appropriate values for a sample with an electron concentration of about 4×10^{18} cm^{-3} are:

T (°K)	μ_H (cm^2/v-sec)	b	c (10^6 cm^4/v^2-sec^2)	d
294	610	0.061	−0.062	0.180
77	710	0.074	−0.082	0.24

Thus the ratio c/b is $-1.02(\pm0.03)$ at room temperature and deviates only by a relatively small amount at 77°K. The values at 77°K have errors of about ten percent.