Lawrence Berkeley National Laboratory
Recent Work

Title
ON THE UNIVERSAL FERMI INTERACTION

Permalink
https://escholarship.org/uc/item/6vd2g33w

Author
Bludman, Sidney A.

Publication Date
1958-04-08

UNIVERSITY OF CALIFORNIA

Ernest O. Lawrence

Radiation

Laboratory

BERKELEY, CALIFORNIA

DISCLAIMER

UNIVERSITY OF CALIFORNIA

Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

ON THE UNIVERSAL FERMI INTERACTION

Sidney A. Bludman

April 8, 1958

ON THE UNIVERSAL FERMI INTERACTION

Sidney A. Bludman

Radiation Laboratory
University of California
Berkeley, California

April 8, 1958

ABSTRACT

The parity-nonconserving, V-A form of Fermi interaction is derived from a principle of invariance under a continuous group of transformations, in analogy with the ordinary gauge-invariance derivation of the minimal electromagnetic interaction of charged particles. This assumption is a stronger restriction on the form of Fermi interactions than that invoked by Sudarshan and Marshak, Gell-Mann and Feynman, and Sakurai, and leads to additional predictions that are subject to experimental check. If these transformations were symmetry transformations of the entire Lagrangian, then the β- and μ-decay coupling constants would be precisely equal. The implications of extending this Fermi gauge invariance to a group depending on space-time functions is discussed.

The possibility that Fermi interactions involving change of strangeness are unallowed is considered, and the results of assuming a universal Yukawa V-A parity-nonconserving interaction are tabulated. Such a Yukawa interaction, involving one new coupling constant, leads to reasonable K meson and hyperon decay rates and allows π meson decay into $\mu + \nu$ without any appreciable decay into $e + \nu$.

ON THE UNIVERSAL FERMI INTERACTION* +

Sidney A. Bludman

Radiation Laboratory
University of California
Berkeley, California

April 8, 1958

I. INTRODUCTION

The recent experimental evidence on the electron asymmetry from polarized nuclei or muons, on the electron polarization, on the nuclear recoil, and on the μ-decay ρ value tends to indicate that in both β and μ decay the four-fermion interaction is of the same strength g and of the same V-A form,

$$g \, \bar{\psi}_1 \, \gamma_\mu \, \tfrac{1}{2}(1 + \gamma_5) \, \tau_+ \, \psi_1 \, \bar{\psi}_2 \, \gamma_\mu \, \tfrac{1}{2}(1 + \gamma_5) \, \tau_- \, \psi_2 \; + \text{h. c.} \tag{1}$$

Here $\tau_\pm$ are charge-raising and -lowering operators and ψ_1 refers to the electron-neutrino, ψ_2 to the neutron-proton or muon-neutrino field operators. It has also been conjectured that the same interaction obtains in electron or μ capture and perhaps in other Fermi interactions, although definitive experiments have not yet been done.[1]

A theoretical basis for this V-A form of interaction has recently been suggested by Sudarshan and Marshak,[2] Feynman and Gell-Mann,[3] and Sakurai.[4] These authors all assume that the Fermi interaction obtains between pairs of charged and neutral fermions and then, motivated by principles of "chirality invariance",[2] use of two-component fields,[3] or "mass-reversal invariance",[4] they assume, that the Fermi interactions are invariant under the discrete transformation

$$\psi \to \psi' = i \, \gamma_5 \, \psi \tag{2'}$$

applied to all Fermi fields separately. They are then led directly to the parity-nonconserving charge-exchange V-A interaction, Eq. (1).

Now the vectorial nature of the Fermi interaction suggests a stronger assumption analogous to the assumption of gauge invariance in electrodynamics. In this paper we consider the consequences of assuming for the Fermi interactions an invariance under a continuous group of transformations applied to various fermions simultaneously. One motivation for this farther-reaching assumption is that the charge-exchange character, expressed by the operators $\tau_{\pm}$ in Eq. (1), can be incorporated more naturally. A second motivation is that certain conservation laws, to be discussed in Section III, would follow if the entire Lagrangian were invariant under these continuous Fermi gauge transformations. Since the mass terms, and probably also the strong interactions, are not invariant under these transformations, we will be led to speculate on the origin of the strong interactions and the blocking of the symmetry of the weak interactions.

In Section III we also discuss two structure problems connected with the weak interaction: the ρ value, and the Gamow-Teller Fermi coupling constant ratio. Section IV discusses the possibility of allowing Fermi gauge transformations which depend arbitrarily on space-time. This leads to a vector meson intermediary field in Fermi interactions, with serious implications that are discussed.

We are inclined to believe that the Fermi interactions do not allow changes in strangeness. Since this philosophy--which is in agreement with experimental results on the absence of hyperon β decay--is more restrictive than the usual one,[5] we are led to introduce in the Appendix a universal weak Yukawa interaction. This additional interaction (with one arbitrary coupling constant) is sufficient to explain the observed rates of most meson and hyperon decay processes, and makes verifiable predictions about the asymmetries and nucleon polarizations to be expected in hyperon decay.

The weak interactions have been generally regarded solely as destructive of the reflection and charge-conjugation symmetry laws. The point of view suggested in this paper, on the other hand, is that the weak interactions actually show some symmetry not shared by the strong interactions.

II. A SYMMETRY PRINCIPLE FOR THE FERMI INTERACTIONS

1. Fermi Gauge Transformations

If mass differences are neglected, the members of a charge multiplet are distinguished only by the electromagnetic interaction. This equivalence can be expressed for the neutron-proton, electron-neutrino, and muon-neutrino systems by arranging these fermions into two component spinors in charge space, $\psi_i = (pn), (ve), (v\mu)$, and asserting invariance under arbitrary unitary unimodular transformations.

We assume that the weak interactions are those distinguishing $\psi_+ = \frac{1}{2}(1 + \gamma_5)\psi$ from $\psi_- = \frac{1}{2}(1 - \gamma_5)\psi$, in the same way as the electromagnetic field distinguishes between the projections $\frac{1}{2}(1 + \tau_3)\psi$ and $\frac{1}{2}(1 - \tau_3)\psi$. Then we identify the weak interactions as those that are invariant under the transformation

$$\psi \rightarrow \psi' = \exp\left[i \, \frac{1}{2}(1 + \gamma_5) \, \underline{\tau} \cdot \underline{\omega} \right] \psi \tag{2}$$

This transformation is admitted by the interactions $\overline{\psi}\gamma_\mu\psi$ and $\overline{\psi}\gamma_\mu\gamma_5\psi$. Because $\overline{\psi}\sigma_{\mu\nu}\psi$, $\overline{\psi}\gamma_5\psi$, and $\overline{\psi}\psi$ couple ψ_+ and ψ_-, such terms in the Lagrangian, including particularly the ordinary mass term, are not invariant under transformation (2).

The transformation (2) is a canonical transformation generated infinitesimally by the charge-space vector

$$\underline{F} = \int d\sigma_\mu \, \underline{J}^\mu , \tag{3}$$

where

$$\underline{J}^\mu = \sum_j i \, \overline{\psi}_j \, \gamma_\mu \, \frac{1}{2}(1 + \gamma_5) \underline{\tau} \, \psi_j \tag{4}$$

is an Hermitian current density composed additively of the fermion doublets introduced. By use of the anticommutation relations for ψ_j, Eq. (4) may be written more symmetrically:

$$\underline{J}^\mu = \sum_j \frac{i}{2}\left\{ \overline{\psi}_j \, \gamma_\mu \, \frac{1}{2}(1 + \gamma_5)\underline{\tau} \, \psi_j - \overline{\psi}_j^c \, \gamma_\mu \, \frac{1}{2}(1 - \gamma_5) \underline{\tau}^T \psi_j^c \right\}, \tag{4'}$$

where $\psi^c = C\overline{\psi}$, with $C\gamma_\mu C^{-1} = -\gamma_\mu^T$, is the charge conjugate to ψ.

Thus we have

$$\left[\underset{\sim}{F}, \psi_i\right] = -\tfrac{1}{2}(1+\gamma_5)\underset{\sim}{\tau}\,\psi_i,$$

$$\left[\underset{\sim}{F}, \psi_i^{\,c}\right] = \tfrac{1}{2}(1-\gamma_5)\underset{\sim}{\tau}^T\,\psi_i^{\,c}.$$

(5)

Particle and antiparticle contribute with opposite signs to F, which we entitle the Fermi charge (with three components!) or Fermi spin.

Since F_1 and F_2 do not commute with the electric charge, states of definite charge cannot be diagonal in $F_{1,2}$ (any more than they can be diagonal in the charge-conjugation operator, say). Indeed it is precisely the electromagnetic field that distinguishes the members of the degenerate ψ_i doublets.

Note that the upper and lower members of ψ are positive and neutral for the nucleons and neutral and negative for the leptons. This is summarized in the formula for the charge

$$Q = \tau_3 + l/2,$$

where the charge displacement l is 1 for nucleons and -1 for leptons.

2. Minimal Coupling

In addition to assuming Fermi gauge invariance of the weak interactions, we also assume that the weak interactions are specifically the interactions of this current with itself,

$$\mathcal{L}_{int} = g\,\underset{\sim}{J}_\mu \cdot \underset{\sim}{J}_\mu = \sum_{i,j}\left[g\;\bar\psi_i\gamma_\mu(1+\gamma_5)\tau_+\psi_i\right]\left[\bar\psi_j\gamma_\mu(1+\gamma_5)\tau_-\psi_j\right]$$

$$+\,\left(\tfrac{g}{4}\right)\left[\bar\psi_i\gamma_\mu(1+\gamma_5)\tau_3\,\psi_i\right]\left[\bar\psi_j\gamma_\mu(1+\gamma_5)\tau_3\,\psi_j\right]$$

(6)

This assumption corresponds exactly to the assumption of minimal interaction in electrodynamics.

The interaction (6) contains three kinds of terms:

(a) The part involving $\tau_\pm = \frac{1}{2}(\tau_1 \pm i \tau_2)$ and $i \neq j$,

$$\sum_{i \neq j} g(i\, \tau_+\, i)\, (j\tau_-\, j) = g\left[(pn)\,(ev) + (pn)\,(\mu v) + (ve)\,(\mu v) + h.c.\right] , \tag{7}$$

leads to the familiar parity-nonconserving V-A charge-exchange interactions. (We use an abbreviated notation in which i, j, p, n, e, μ, etc. stand for the corresponding field operators and the spin matrices $\gamma_\mu (1 + \gamma_5)$ have been suppressed.)

(b) The part involving $\tau_\pm$ and $i = j$

$$\sum_i g(i\, \tau_+\, i)\, (i\, \tau_-\, i) = g\left[(pn)\,(np) + (v\,e)\,(e\,v) + (v\mu)\,(\mu v)\right] \tag{8}$$

leads to weak lepton-lepton and nucleon-nucleon scattering processes which have been already suggested by Feynman and Gell-Mann.[3]

(c) The part involving τ_3 leads to

(i) weak nucleon-nucleon scattering processes,

$$\frac{g}{4}\,(pp-nn)\,(pp-nn) ; \tag{9}$$

(ii) weak nucleon-lepton processes,

$$\frac{g}{2}\,(pp-nn)\,(2\,vv - ee - \mu\mu) ; \tag{10}$$

and

(iii) weak lepton-lepton scattering processes,

$$g\left\{(vv)\,(vv) + \tfrac{1}{4}(ee)\,(ee) + \tfrac{1}{4}(\mu\mu)\,(\mu\mu) + \tfrac{1}{2}(ee)\,(\mu\mu) - (vv)\,(ee) - (\mu\mu)\,(vv)\right\}. \tag{11}$$

Provided the spinor fields anticommute, like V-A, we find that the V-A interaction is invariant under reordering of the four spinors. Hence some of the terms in Eqs. (9) and (11) are equivalent, except for coefficient, to those included in Eq. (8). Consequently:

(a) The Feynman—Gell-Mann processes (ve) (ev) and (v μ) (μ v) are actually not expected on the present theory because of a cancellation between the terms in Eqs. (8) and (11).

(b) The weak process (pn) (np), if it could be observed, would actually occur with a coupling constant $\frac{f}{4}$.

(c) Other scattering processes not considered by Feynman and Gell-Mann are suggested by Eq. (10).

These results, which may be subject to experimental check, are necessary consequences of our development. If τ_+ and τ_- have been introduced in order to obtain the ordinary charge-exchange interactions (7), then τ_3 must occur if a group is to be defined.

3. How Universal is the Fermi Interaction

Because each ψ_i was assumed to contain a neutral and a charged-particle field, pairs like (e⁻ e⁻) or (e⁻ μ⁻) do not appear. This excludes the decays

$$\mu^- \to e^- + \gamma \quad \text{or} \quad e^- + e^+ + e^- ,$$
$$K^0 \to \mu^+ + e^- \quad \text{or} \quad \nu + \bar{\nu} \quad -- \tag{12}$$

which have, in fact, never been observed.

The Fermi gauge transformations can certainly be extended to other pairs consisting of members of a charge multiplet such as $(\Xi^0 \Xi^-)$, $(\Sigma^+ X^0)$, $(Y^0 \Sigma^-)$, where $X^0 = \frac{1}{2}(\Lambda^0 + \Sigma^0)$, $Y^0 = \frac{1}{2}(\Lambda^0 - \Sigma^0)$. The rate of β decay $\Xi^- \to \Xi^0 + e^- + \bar{\nu}$ depends on the yet-to-be-discovered $\Xi^0 - \Xi^-$ mass difference. The β-decays, $\Sigma^\pm \to \Sigma^0$, proceed at a rate slower than 6 per second.

It would seem, on the other hand, to be an open question whether or not pairs like $(p \Lambda^0)$, consisting of members of _different_ charge multiplets, are subject to Fermi gauge transformations. Inclusion of such a pair in the Fermi interaction was suggested by Gell-Mann[5] in order that the strange-particle decays be, at least in principle, a consequence of some universal Fermi interaction. Until we have an over-all symmetry principle assigning both weak and strong interaction properties to all particles, our philosophy ought to be to allow the presence or absence of decays like

$$\Sigma, \Lambda \to n + e + \bar{\nu} \tag{13}$$

to tell us what is the structure seen by the Fermi interactions.

The Appendix to this paper presents a treatment of meson and hyperon decays based on a phenomenological universal weak Yukawa V.-A interaction. Such a direct Yukawa interaction (which might actually follow from the Fermi interactions) actually gives reasonable values for the meson and hyperon decay rates. If such a weak Yukawa interaction appears as an elementary interaction alongside the conventional Puppi-Gell-Mann tetrahedron, then the scheme of the weak interactions is that of Fig. 1, instead of the Puppi-Gell-Mann tetrahedron.

III. IS THE FERMI CURRENT CONSERVED?

Invariance of the action integral $\int \mathcal{L} d^4 x$ under an n-parameter group of continuous transformations is equivalent to a set of n integral conservation laws. Electromagnetic charge is, so far as we know, absolutely conserved, so that ordinary gauge-invariance must be an exact symmetry law. If the Fermi gauge transformations were absolute symmetry transformations, $\underline{F}$ would be absolutely conserved. This would give expression to the conservation of Fermi charge along with electromagnetic charge and would explain[3] the at least approximate equality of the V and A coupling constants in β and μ decay. In this section we wish to consider the limitations, imposed by the strong interactions, to the conception that $\underline{F}$ is conserved and Eq. (2) is a symmetry operation of the Lagrangian.

1. Comparison of Coupling Constants in μ and β Decay. Size Effects

Feynman and Gell-Mann, in order to explain the apparent equality of the coupling constants g^β and g^μ in β and μ decay, have considered introducing additional meson-formation interactions so that the total Fermi current, consisting of the fermion part in Eq. (4) plus a part bilinear in the meson fields, may be conserved. Because for spinless particles the obvious analogue to γ_5 is identically zero, this is difficult to envisage theoretically. In addition, the experimental evidence on the ρ value in μ decay and on the ratio of Gamow-Teller and Fermi coupling constants in β-decay, if taken seriously, requires two different kinds of structure in these weak interactions:

(a). Size effects have been invoked[6,7] in μ decay to explain the value
ρ = 0.68 ± 0.02 < 3/4 measured.[8] The simplest kind of nonlocality[6] in which the

($\nu\mu$) and ($e\nu$) currents are assumed to interact at two different points leads to $\rho > \frac{3}{4}$ if the weak interaction is supposed to take place through a single intermediary field. With a more complicated three- or four-point interaction involving fermions in intermediate states, a ρ value less than $\frac{3}{4}$ can be obtained.[7] In any case, g^μ times a form factor (~ 0.9) is what appears in the μ lifetime and what is remarkably equal to g^β.[9]

(b) The evidence indicates[10] that the Gamow-Teller and Fermi coupling constants are not precisely equal in β decay.

$$g^\beta_A / g^\beta_V = 1.15 \pm 0.05 \, . \tag{14}$$

If the bare coupling constants are equal this can be attributed only to π or K meson corrections that are different for V and A couplings.[11] If the Fermi current were absolutely conserved there would be no such corrections.

The present data thus indicate finite but small structure corrections to the idea of a point Fermi interaction with exactly universal coupling constants. This interpretation is subject to additional verification in two ways:

(a) g^μ and g^β can be carefully compared by measuring the ratio of μ capture to K capture in the same nucleus. Because, in the two cases, the same pion structure but far different momentum transfers are involved, this experiment probes the μ-decay structure invoked in connection with the ρ value.

(b) The effect of the pion cloud can be studied by comparing μ capture and μ decay in which the same momentum transfer is involved. If the μ-capture/ μ-decay ratio were studied as a function of Z, one might hope to smooth out the uncertainties connected with nuclear structure.

Judging from the magnitude of the deviation of ρ from $\frac{3}{4}$ and of g_A from g_V in β decay, 10-20% structure effects might be expected in experiments of this kind.

2. Role of the Strong Interactions

If all particles were originally massless, so that the Fermi gauge transformations were symmetry operations of the Lagrangian, the physical particles would, in the presence of the Fermi interactions, remain of zero mass and of definite (left) handedness. They would still remain so in the presence of the minimal electromagnetic interactions, which are of the form $\bar{\psi} \gamma_\mu \psi A_\mu$. Physical particles

would then be labeled entirely by the quasigeometrical attributes of handedness and charge. Anomalous magnetic-moment interactions $\bar{\Psi}\sigma_{\mu\nu}\psi F^{\mu\nu}$ and scalar or pseudoscalar meson-interaction terms in the Lagrangian, on the other hand, do not admit the Fermi gauge transformations. This tempts one to speculate that the inertial terms $\bar{\Psi} m \psi$, like any $\bar{\Psi}\sigma_{\mu\nu} F^{\mu\nu}\psi$ terms, are related to those same mysterious effects that introduce the strong meson couplings $\bar{\Psi}\gamma_5 \tau \cdot \phi \psi$ or $\bar{\Psi}\phi\psi$ into the Lagrangian. According to this view, all these effects are common consequences of the breakdown of the symmetry, revealed in the weak interactions, by the introduction of some dimension of mass or length.[12]

This situation corresponds qualitatively to the fact that the neutrino, which has neither strong mesonic nor electromagnetic coupling, is massless, whereas baryons that have strong interactions are heavy, and leptons that have electromagnetic but not mesonic interactions, are light. It is important to note that because V and A interactions admit the Fermi gauge group, the lepton mass cannot be attributed entirely to minimal electromagnetic interaction, but must be due, in the first place, to those same mysterious effects which introduce a parameter of mass dimensionality.

One interesting way for a symmetry law to be broken has been suggested by the work of Heisenberg:[12] perhaps the Lagrangian contains no mass terms and admits the Fermi gauge group, but regularity conditions on the propagators produce the observed masses, destroy the symmetry, and at the same time introduce the effects of strong interaction. (In Heisenberg's work the Lagrangian contained the isosymmetry of the strong interactions which was somehow destroyed by the weaker electromagnetic effects introduced along with the commutation relations.) We find it easier to see the greatest symmetry, closest to the vacuum, in the weakest interactions--gravitation, β decay and meson and hyperon decay, electromagnetism--because these interactions seem more susceptible to a "geometric" treatment. We see little hope for incorporating the strong interactions into the space-time continuum: The attempt to develop interaction as consequence of a local symmetry principle, the idea of the b field, has not been fruitful where originally proposed in connection with the π-meson interactions[14,15] but, as discussed in the next section, is a possibility for the weak interaction.)

IV. LOCAL FERMI GAUGE TRANSFORMATIONS

In Eq. (2) only restricted Fermi gauge transformations (ω a arbitrary constant) were considered. If now ω is promoted to be an arbitrary vector function of space-time, $\omega(x)$, then a vector-meson field transforming infinitesimally as

$$b_\mu \rightarrow b_\mu + 2 \, b_\mu \times \omega + \partial_\mu \, \omega \tag{15}$$

must be introduced[13] in order that the derivative

$$D_\mu \psi = (\partial_\mu - i \tfrac{1}{2}(1 + \gamma_5) \, \tau \cdot b_\mu) \, \psi \tag{16}$$

transform convariantly. This approach has the merit of leading directly to a vector interaction

$$\mathcal{L}_{int} = J_\mu \cdot b_\mu \tag{18}$$

with the current defined in Eq. (4), without the additional assumption of a specific minimal current interaction.

If this b field is to be interpreted as a real particle, its quanta must be massive in order to explain why b particles have not been detected as products of K- or π-meson decay and in order to explain the effectively local nature of the Fermi interaction. At least two difficulties argue against a realistic interpretation of the b field. In the first place, as mentioned above, such an intermediary particle would raise the μ-decay ρ value above $\frac{3}{4}$, while presently published measurements report a value $\rho = 0.68 \pm 0.02$.[16] In the second place, any charged spin-one particle has a singular nonrenormalizable electromagnetic interaction.

Incidentally, because of its V- coupling, b-meson corrections cannot alter the basic V-A lepton interaction to effect the calculated $\pi \rightarrow e + \nu / \pi \rightarrow \mu + \nu$ ratio. As noted above, the b and π meson cannot be directly responsible for all the mass of the μ meson.

V. CONCLUDING DISCUSSION

This development presupposes that we can treat the weak interactions at least semiquantitatively, without attempting to deal with the strong interactions. A Fermi current has been derived from a continuous group of transformations, which presumably would be symmetry operations in the absence of strong-interaction effects. The weak interactions are supposed to be the interactions of this Fermi current with itself, and possibly with spin-zero mesons.

This assumption goes beyond earlier ones[3,4,5] in three respects:

(a) A continuous group of transformations described in Eq. (2), has been introduced here in frank analogy with gauge invariance, general covariance and isotopic spin invariance, in order to give expression to the at-least-approximate conservation of Fermi charge observed in the near equality of Fermi coupling constants. (As stated in Section III we imagine the Fermi gauge invariance to be blocked, at least partially, by those same phenomena giving rise to strong interactions and mass effects.) Invariance under a discrete group like that in Eq. (2') does not imply any current conservation at all.

(b) We incorporate the three charge operators τ_+, τ_-, and τ_3 into our symmetry transformation instead of assuming[3,4,5] directly the charge exchange character of the interaction. Because we allow charge-retention Fermi interactions (through τ_3) in addition to the charge-exchange interactions (7) and (8) we expect weak neutrino-nucleon but no neutrino-electron scattering processes.

(c) Since we see no reason why the Fermi interaction need extend to all fermion pairs, we do not expect hyperon β decays involving strangeness change. If this turns out to be the case, we must assume an additional universal weak Yukawa process to describe meson and hyperon decays.

The consequences of assuming Fermi gauge invariance are in any case far-reaching enough to permit an experimental decision.

APPENDIX

In this appendix we wish to record the results of assuming a weak interaction between a meson field ϕ of mass M, and particular pairs of fermions

$$(g/M)\ 2^{-\frac{1}{2}}\partial_\mu\ \phi\ \overline{\Psi}\gamma_\mu\ (1 + \gamma_5)\psi. \tag{A1}$$

As suggested in the right side of Figure 1, this interaction is assumed to involve only baryons (PΛ), (N Λ), (PΣ), (NΣ'), (ΞΛ) belonging to <u>different</u> charge multiplets, and only the lepton pair (ν μ). From the rate 0.39×10^8 sec^{-1} for π decay, we fix

$$g^2/4\pi = 3.67 \times 10^{-15}. \tag{A2}$$

The other decay rates are then calculated from this one coupling constant and compared with experiment in Table I. The rate for $K \to \mu + \nu$ has been given previously.[17] For the baryon decays, no attempt has been made to calculate branching ratios that would follow, for example, from the $\Delta I = \frac{1}{2}$ rule.

This weak Yukawa interaction discriminates between muon and electron in such a way as to allow the decay $\pi \to \mu + \nu$ while preventing any appreciable $\pi \to e + \nu$ decay. The strong π coupling to (PN) of course still allows, in addition, π decay through the Fermi interactions that are known to involve (PN) (ν e) as well as (PN) ($\nu\mu$). The experimental upper limits on the ratio of decay modes of e and μ suggest, however, that these Fermi interactions can be responsible for no more than one-tenth of all π decays.(A recent estimate[18] of π decay through the channel $\pi \to \eta + \overline{\eta} \to \mu + \nu$ shows appreciable damping of the pion-nucleon coupling constant. This illustrates how this channel may not contribute significantly in comparison with the direct Yukawa coupling assumed here. It also shows how the amplitude for K decay through $\eta + \overline{\eta}$ can be comparable with that for π decay through $\eta + \overline{\eta}$ even though the strong coupling constants are somewhat unequal.)

The interaction (A1) leads to a ratio of p-wave to s-wave emission

$$\tan \nu\ (1 - X_-^2)/(1 - X_+^2)^{\frac{1}{2}},$$

which is close to unity in hyperon decay. Here $X_\pm = M/(M_1 \pm M_2)$, where M_1 and M_2 are the baryon masses. In the decay of polarized hyperons,[19] large

positive asymmetries $a = \sin 2\nu$ and longitudinal polarizations $P_L = -a$ are therefore obtained. The transverse nucleon polarizations $P_T = \cos 2\nu$ are, on the other hand, in the plane defined by the decay and the hyperon spin, and relatively small. In this calculation the small effects of final-state interaction have been neglected.

The experimental evidence indicates[20] $|a| > 0.77 \pm 0.16$ in Λ decay, which is consistent with the calculated value. The preliminary data probably indicates small asymmetries in Σ decay,[21] which would be in disagreement with the calculated values listed in Table I. (Such an experimental result would also disagree with the $\Delta I = \frac{1}{2}$ rule, which predicts large asymmetries of opposite signs in at least two of the Σ-decay modes.) In any case the chirality-nonconserving strong interactions can easily wash out the asymmetries and polarizations calculated on the basis of the simple V-A interaction.

Table I.

Decays involving mesons. The rates are calculated from the universal weak Yukawa interaction (A1) with coupling constant (A2) derived from the π life-time. The asymmetry α and transverse polarization P_T of the decay baryon in hyperon decay are given in the convention of Lee and Yang.[19]

Process	Calculated decay rate(sec^{-1})	Observed decay rate(sec^{-1})[22]	α	P_T
$K \to \mu + \nu$	55×10^{6}[17]	48×10^{6}	...	...
$\Lambda^0 \to p + \pi^-$		0.234×10^{10}		
$\Lambda^0 \to n + \pi^+$	0.10×10^{10}	0.126×10^{10}	0.89[23]	0.45
$\Sigma^+ \to p + \pi^0$		0.59×10^{10}		
$\Sigma^+ \to n + \pi^+$	0.62×10^{10}	0.69×10^{10}	0.98	0.18
$\Sigma^- \to n + \pi^-$		0.64×10^{10}		
$\Xi^- \to \Lambda^0 + \pi^-$	0.21×10^{10}	$(0.005 - 0.2) \times 10^{10}$	0.95	0.30

REFERENCES

1. G. Puppi, Nuovo cimento 5, 587 (1948);

   O. Klein, Nature 161, 897 (1948);

   Lee, Rosenbluth, and Yang, Phys. Rev. 75, 905 (1949);

   J. Tiomno and J. Wheeler, Revs. Modern Phys. 21, 153 (1949).

2. E.C.G. Sudarshan and R.E. Marshak, Padua-Venice International Conference, September, 1957; Phys. Rev. 109, 1860 (1958).

3. R.P. Feynman and M. Gell-Mann, Phys. Rev. 109, 193 (1958).

4. J.J. Sakurai, Nuopoint Nante (published 1958).

5. M. Gell-Mann, Suppl. Nuovo cimento 4, 848 (1956).

6. T.D. Lee and C.N. Yang, Phys. Rev. 108, 1611 (1957).

7. S. Bludman and A. Klein, Phys. Rev. 109, 559 (1958).

8. Sargent, Rinehart, Lederman, and Rogers, Phys. Rev. 99, 885 (1955);

   K. Crowe, Bull. Am. Phys. Soc., Ser. II, 2, 206 (1957);

   L. Rosenson, Phys. Rev. 109, 958 (1958).

9. This observation is orginally due to R. Gatto, UCRL (private communication).

10. See the review by L. Michel, Revs. Modern Phys. 29, 223 (1957).

11. R. Finkelstein and S.A. Moszkowski, Phys. Rev. 95, 1695 (1954);

    S.S. Gerschtein and Iu. B. Zeldovich, Soviet Physics (JETP) 2, 576 (1956);

    B. Stech, Z. Physik 145, 319 (1956);

    M. Ross, Phys. Rev. 104, 1736 (1956).

12. See J. Schwinger, Ann. Physics 2, 407 (1957).

13. W. Heisenberg, Revs. Modern Phys. 29, 269 (1957).

14. C.N. Yang and R.L. Mills, Phys. Rev. 96, 191 (1954).

15. S.A. Bludman, Phys. Rev. 100, 372 (1955).

16. A recent calculation by S.M. Berman (preprint to be published) reports, however, that the electromagnetic corrections to μ decay have been underestimated heretofore, so that the measured ρ value is effectively greater than 0.68.

17. S.A. Bludman and M.A. Ruderman, Phys. Rev. 101, 910 (1956). Onedd and collaborators, in Nuclear Phys. 1, 445 (1956) and earlier papers, obtain a different rate for $K \to \mu + \nu$ because, in the interaction (A1), they omit the factor M^{-1} which is different for π and for K decay.

18.   M. L. Goldberger and S. B. Treiman, preprint (to be published).

19.   T. D. Lee and C. N. Yang, Phys. Rev. 108, 1645 (1957).

20.   L. Stevenson, A. P.S. Stanford meeting, 1957.

21.   Walter H. Barkas (UCRL), private communication.

22.   The experimental transition rates into each mode are taken from the
       survey by M. Gell-Mann and A. H. Rosenfeld, Jr., Ann. Rev. Nuclear
       Sci. 7, (1957).

23.   J. J. Sakurai, Phys. Rev. 108, 491 (1957).

CAPTION

Fig. 1. The basic weak Yukawa interaction that is assumed, along with the
Puppi triangle§ in this paper.

ν_e

ν_μ

N⁰

K⁺

P⁰