On the Decay Interactions of Strange Particles

Yoshihiko MIYACHI

Research Institute for Theoretical Physics, Hiroshima University
Takehara-machi, Toyota-gun, Hiroshima-ken

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Under the assumption that the Konopinski-Uhlenbeck interaction works as an origin of weak interactions in which the existence of strange particles should be taken into account, the decay events $K^0_{\mu\alpha}, K^0_{\mu\beta}, K^0_{\nu\beta}$ and $K^0_{\nu\beta}$ are investigated. The available data seem to be favourable to our predictions, though it is premature to draw any definite conclusions. Some remarks are also made about the $\beta$-decay of Hyperons and the $K$-meson decay into two leptons.

§ 1. Introduction

Since the discovery of the first $V$-event by Rochester and Butler in 1947, the existence of a number of particles with curious properties, the so-called strange particles, has been established. Various properties of these particles, especially their copious productions and their long lifetimes were described consistently in terms of the beautiful scheme of Nishijima-Gell-Mann-Pais, in a somewhat qualitative manner, and now it is generally accepted that, besides the strong and the electromagnetic interactions, there exists a group of interactions called weak interactions. In spite of a wide variety of the nature of particles which participate in these interactions, we find a remarkable fact that the strength of all these couplings is almost of the same order of magnitude ($\approx 10^{-13}$ in the unit $b=c=\hbar=1$). It is reasonable, therefore, to assume that all these weak interactions originate in a single interaction which has a universal character to some extent. From such a point of view the weak Fermi interaction (F-int.) seems to be of special interest, since it is the interaction between two pairs of Fermions and we may possibly derive from it, in collaboration with the strong interactions, the other kinds of interactions, such as the weak Boson-Fermion and the weak Boson-Boson interactions.

Many investigations have been made under the assumption that the weak F-int. acts as an origin of various weak interactions. It seems to the present author, however, that such a hypothesis neither has any a priori reason nor is so efficient in explaining various phenomena. Indeed, it has been pointed out by Ōeda and Wakasa that, in order to get a unified description of all phenomena involving strange particles as well as familiar nucleons, pions and leptons in terms of the strong, the electromagnetic and the

* In this picture of the weak interactions, the concept of the F-int. must be extended so as to include four-baryon processes as well as the well-known neutrino processes.
weak $F$-int., it is necessary to add a more complicated character to the $F$-int., e.g., the process dependence of the coupling type. Such a restriction is rather artificial and ad hoc, and is unsatisfactory from the viewpoint that the primary interaction must be of a universal character.

In the analysis of the decay processes of charged $K^0$ and $K^+$ by Furuichi et al., similar situations did occur. According to their calculations the energy spectrum of the secondary electrons (muons) has a large distribution in the high energy region for most of the coupling types ($S$, $V$, $A$, $P$) of the $F$-int., both for scalar and vector $K$-mesons. They also found that, for the tensor coupling in the case of spin 0 $K$-meson, there are two peaks in the electron (muon) distribution, one being in the low energy region and another in the high energy region. The experimental results give a large distribution of electrons (muons) in rather low energy regions. Hence, in order to get the best fit to the Rochester data, appropriate combinations of $S(T)$- and $S(P)$-couplings for $K^0$ and $S(T)$- and $S(A)$-couplings (or $V(P)$- and $V(T)$-couplings) for $K^+$ have been required.

Here it is quite interesting to observe the following points. Among various events that are realized by the weak interactions, we have, on the one hand, many phenomena which can be settled without considering the existence of strange particles. The $\beta$-decay of nucleons and the $\mu^-$-capture, for example, belong to this class. On the other hand, there are also phenomena in which the existence of strange particles should inevitably be taken into account. The decays of Hyperons and $K$-mesons are contained in this class. In the first class of phenomena the weak $F$-int. has gained a brilliant success. Yet, in view of the circumstances mentioned above, it seems highly probable that the interactions which have a large applicability to the first class of phenomena are not necessarily responsible to, or at least do not play an important role in, the second class of phenomena. We may assume as well that some new kind of universal interactions other than the usual weak $F$-int. plays an essential role in the weak interactions in which particles with strange properties participate. Along this line of thought we are led to expect that the experimental features of phenomena belonging to the second class will be explained in terms of some universal interaction of a new kind without any further artificial restriction.

In this connection the interaction proposed by Konopinski and Uhlenbeck (KU-int.) about twenty years ago is of particular interest. It is the one-point interaction as is the $F$-int. Furthermore the KU-int. contains a time derivative of the wave function of the neutrino, hence it is, as is well known, more favourable to the emission of high energy neutrinos than the $F$-int. and this situation seems to be of practical value for describing a large distribution of low energy electrons (muons) in charged $K^0$ ($K^+$)-decay.

In order to ascertain the above conjecture, we shall examine in this paper the validity of the KU-int. as an origin of weak interactions in which the existence of strange particles.

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* Strictly speaking, such a classification is not possible because we must take into account all particles that exist in nature. The distinction between these two classes of phenomena may be somewhat obscure, but it has to be understood only in the phenomenological sense.
should be taken into account. In § 2 we look for the most adequate phenomena to test our proposal and give general considerations of their treatment. Using the procedure there explained, we examine in § 3 the \( K_{\mu}^{\pm} \) - and \( K_{\mu}^{0} \)-decay, and the energy spectra of the secondary muons and electrons are compared with those based on the \( F \)-int. In order to clearly show the difference between the \( KU \)-int. and the \( F \)-int., we next consider in § 4 the energy distribution of neutrinos in the \( K_{\rho}^{0} \) \( (K_{\rho}^{\pm}) \)-decay. § 5 is devoted to a discussion of the \( K \)-meson decay into two leptons and the \( \beta \)-decay of Hyperons.

§ 2. General considerations

As has been mentioned in the previous section, we have assumed that the \( KU \)-int. plays an essential role in the second class of phenomena. In those events which contain no strange particles both in the initial and final states, the \( KU \)-int., if it works at all, operates only indirectly, strange particles appearing only in intermediate states. Further, we give a preferential treatment for neutrinos in the \( KU \)-int. Therefore, the most adequate phenomena to test our proposal are those in which we have strange particles and neutrinos either in the initial or in the final state or in both of them. In this paper we are mainly interested in the following phenomena:

\[
\begin{align*}
K_{\mu}^{\pm} & \rightarrow \mu^{\pm} + \nu + \pi^{0}, & K_{\mu}^{\pm} & \rightarrow e^{\pm} + \nu + \pi^{0}, \\
K_{\mu}^{0} & \rightarrow \mu^{\pm} + \nu + \pi^{\mp}, & K_{\mu}^{0} & \rightarrow e^{\pm} + \nu + \pi^{\mp}, \\
K_{\mu}^{\pm} & \rightarrow \mu^{\pm} + \nu, & K_{\mu}^{0} & \rightarrow e^{\pm} + \nu + \pi^{\mp}, \\
\Lambda^{0} (\Sigma^{0}) & \rightarrow P + e + \nu.
\end{align*}
\]

(2.1) \hspace{2cm} (2.2) \hspace{2cm} (2.3) \hspace{2cm} (2.4)

Processes (2.1) — (2.3) are realized by the cooperation of the strong and the weak \( KU \)-int., while the process (2.4) can be realized by the direct \( KU \)-int. among four Fermions. For strong interactions it is desirable to avoid the perturbational treatment as far as possible, hence we adopt the procedure used by Öneda and Wakasa\(^{0} \) and by Furuichi et al.\(^{40} \) in the analysis based on the \( F \)-int.

The starting points of our analysis are:

1. The transition matrix elements are Lorentz invariant.
2. The decay of the \( K \)-meson with lepton secondaries is realized by the collaboration of the strong and the weak \( KU \)-int. which acts only once in the whole course of the decay process (Fig. 1).

In contrast to the five coupling types of the weak \( F \)-int., there are three coupling types in the \( KU \)-int. which involve the time derivative of the neutrino wave function,
On the Decay Interactions of Strange Particles

namely *

vector: \( (\bar{u}\gamma_\mu w)(\bar{\psi}\partial_\mu \varphi) \), \hspace{1cm} (2.5)

tensor: \( (\bar{u}\sigma_{\mu\nu} w)(\bar{\psi}\gamma_\mu \partial_\nu \varphi) \), \hspace{1cm} (2.6)

pseudovector: \( (\bar{u}\gamma_\mu \gamma_5 w)(\bar{\psi}\gamma_\mu \partial_\mu \varphi) \), \hspace{1cm} (2.7)

where \( u, w \) and \( \psi \) are wave functions of three Fermions** and \( \varphi \) is the wave function of the neutrino. Then, from the requirement of the Lorentz invariance, the transition matrix for the processes (2·1) and (2·2) can be written in a very general form:

\[
M = (2\pi)^4 \delta^4(\vec{p} - \vec{p} - \vec{q} - \vec{l}) \bar{\psi}(p) \mathcal{O}_j \psi(q) \phi^*(l) \Phi_\alpha(k) \mathcal{A}^{(i)},
\]

where \( \psi(p), \varphi(q), \phi(l) \) and \( \Phi_\alpha(k) \) are the wave functions of electron (muon), neutrino, pion and K-meson respectively. The \( \mathcal{O}_j \)'s are operators corresponding to the coupling types of (2·5), (2·6) and (2·7). The \( \mathcal{A}^{(i)} \)'s are some functions of the four-momenta \( p, q \) and \( k \) with an appropriate transformation property corresponding to \( \mathcal{O}_j \) and the spin of the K-meson. They are the contributions from all the possible virtual states, which involve the four-momenta of electron (muon) and neutrino only in the combination \( p + q \) since the KU-int. is a one-point interaction as is the F-int.*** For the explicit expressions of \( \mathcal{A}^{(i)} \), we make the same assumption as in reference 4), i.e., the momentum dependence of \( \mathcal{A} \) is restricted only to the lowest order. At present we have no adequate method of discussing the validity of this approximation. But it must be kept in mind that in this paper we are not interested in the absolute value of the matrix elements, but only in the

Table 1. Forms of \( \mathcal{A}^{(i)} \) for processes (2·1) and (2·2)

<table>
<thead>
<tr>
<th>Coupling type</th>
<th>Tensor ( \tau_\mu \varphi_\nu - \tau_\nu \varphi_\mu )</th>
<th>Pseudovector ( \tau_\sigma \varphi_\nu )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scalar ( \phi )</td>
<td>forbidden</td>
<td>( G_{1}^{S}(A) k_\mu ) \begin{tabular}{l} ( G_{2}^{S}(A)(p + q)<em>\mu ) \begin{tabular}{l} ( G</em>{3}^{S}(A) l_\mu ) \end{tabular} \end{tabular}</td>
</tr>
<tr>
<td>Vector ( \phi )</td>
<td>( G_{V}(p) \delta_\mu \alpha k_\nu ) \begin{tabular}{l} ( G_{2}^{V}(p, q) \delta_\mu \alpha (p + q)<em>\nu ) \begin{tabular}{l} ( G</em>{3}^{V}(p, q) l_\nu ) \end{tabular} \end{tabular}</td>
<td></td>
</tr>
</tbody>
</table>

\( \dagger \) Any of these three can be expressed as a linear combination of the other two, but we give all of them explicitly for convenience’ sake.

* We use the KU-int. in its original sense,\(^10\) that is, it involves a time derivative of the neutrino wave function only. Of course, any other coupling type cannot be excluded. But we do not intend to investigate into all cases but confine ourselves to (2·5) — (2·7) as a possible example.
** We assume that all Fermions are particles with spin 1/2.
*** We omit some types of higher order radiative corrections (see reference 4)).
shape of the distribution of secondary electrons (muons) or neutrinos. In Table 1 we record the possible forms of $A^{\pi^{\pm}}$ for the processes $(2 \cdot 1)$ and $(2 \cdot 2)$. Owing to the vanishing of the neutrino mass we cannot discuss the parity of the $K$-meson, so we here consider the $K$-meson as a scalar or vector particle. For the pseudoscalar or pseudovector $K$-meson we have only to take the $A$ with opposite parity.

It should be noted that, owing to the appearance of $q$ in $O$, and to the fact that $q_{\mu}^2=0$, the four-momenta $p$ and $q$ do not necessarily appear in the symmetrical combination $p+q$ in the matrix elements $(2 \cdot 8)$. This differs from the case of the $F$-int., where the matrix elements always contain $p$ and $q$ in such a combination.

By using these matrix elements the transition probability is easily obtained and will be given in the following two sections.

§ 3. Energy spectra of electrons (muons) in charged $K_{\ell 3}$ ($K_{\mu 3}$)-decay

In this section we investigate the energy spectra of the secondary electron and muon in the decay processes

$$K^{\pm}_{\ell 3} \rightarrow e^{\pm} + \nu + \pi^0, \quad (3 \cdot 1)$$
$$K^{\pm}_{\mu 3} \rightarrow \mu^{\pm} + \nu + \pi^0. \quad (3 \cdot 2)$$

In general the transition matrix element is given by an arbitrary linear combination of various coupling types tabulated in Table 1, but we here give the result only for each coupling for convenience' sake.

The calculated spectra are: ($b=c=1$)

for scalar $K$-meson

$$P^{\pi^{A}}(E) = (G^{\pi^{A}}/16\pi^3) M^4 (W-E)^4 (M I_5 - I_6),$$
$$P^{\pi^{B}}(E) = (G^{\pi^{B}}/16\pi^3) M^3 (W-E)^4 (M^2 I_5 - 3M I_4 + 3MI_3 - I_2),$$
$$P^{\pi^{C}}(E) = (G^{\pi^{C}}/16\pi^3) M^3 (W-E)^4 (MI_5 - I_6),$$
$$P^{\pi^{D}}(E) = (G^{\pi^{D}}/16\pi^3) M^3 (W-E)^4 (M I_5 - I_6)$$
$$+ (3M^2 + m^2 - 4ME) I_4 - (M^2 + m^2 - 2ME) MI_5, \quad (3 \cdot 3)$$

and for vector $K$-meson

$$P^{V^{A}}(E) = (G^{V^{A}}/48\pi^3) M^3 (W-E)^4 (M I_5 - I_6),$$
$$P^{V^{B}}(E) = (G^{V^{B}}/48\pi^3) M^3 (W-E)^4 [I_5 - (3M - 2E) I_3$$
$$+ (3M^2 + m^2 - 4ME) I_4 - (M^2 + m^2 - 2ME) MI_5],$$
$$P^{V^{C}}(E) = (G^{V^{C}}/24\pi^3) M^5 (W-E)^4 (M I_5 - I_6),$$
$$P^{V^{D}}(E) = (G^{V^{D}}/48\pi^3) M^3 (W-E)^4 [M^2 + 2ME - m^2] MI_5$$
$$- (3M^2 + 4ME - m^2) I_4 + (3M + 2E) I_5 - I_6], \quad (3 \cdot 4)$$
On the Decay Interactions of Strange Particles

\[ P_3^{x(p)}(E) = \left( G_{x(p)}^{x}/48\pi^3 \right) M^3(W-E)^4 \left[ -I_2 -(M-2E)I_3 \right. \]
\[ \left. + (3M^2+m^2-4ME)I_4 -(M^2+m^2-2ME)MI_5 \right], \]

where \( M, m \) and \( \kappa \) are the masses of \( K \)-meson, electron (muon) and pion respectively. \( W \) is given by

\[ W = (M^2+m^2-\kappa^2)/(2M), \]

and \( I_2, I_3 \cdots \) are the functions defined by

\[ I_n = \int_0^{\pi} (p\sin \theta d\theta)/(M-E+p\cos \theta)^n. \]

The curves of these spectra are given in Fig. 2 and Fig. 3. In what follows we shall discuss these results by comparing them with experimental data and with the results obtained by Furuichi et al.\(^5\) on the basis of the primary \( F \)-int.

1. Charged \( K_{\mu3} \)

Among various coupling types of the \( KU \)-int., the \( G_{x(A)}^{x(A)} \) coupling for scalar \( K \)-meson and \( G_{v(T)}^{x(p)} \)-coupling for vector \( K \)-meson give the results which fit the experimental data rather well. Our results almost coincide with the best result obtained by Furuichi et al.\(^5\) (an appropriate combination of the \( S(T) \)- and \( S(A) \)-coupling) except a slight difference in the high energy end of the distribution. Here it should be noted that all couplings in Table 1 have only one peak in the energy distributions and there is no single coupling type which has two peaks, contrary to the \( S(T) \)-coupling of the \( F \)-int. In the Rochester data for charged \( K_{\mu3} \) the second
maximum in the high energy region of the muon distribution is not observed, therefore we do not necessarily require the $S(T)$-coupling if we only have some coupling type which gives a large distribution of the low energy muons. Practically the $G_3^{S(A)}$-coupling of the $KU$-int. differs from the $S(P)$-coupling of the $F$-int. only by a factor $(lq)$, which is reduced in the rest system of the $K$-meson to

$$(lq) = -M(W-E).$$

This factor favours the predominant emission of muons of lower energy than in the case of the $F$-int. and shifts the distribution to the low energy regions.

2. Charged $K_{e3}$

The agreement with the Rochester data for charged $K_{e3}$ is less satisfactory than in the case of $K_{e3}$, if we use only one coupling type of the $KU$-int. Nevertheless, the $G_3^{S(A)}$-coupling or the $G_3^{P(P)}$-coupling again yields almost the same result as that obtained in reference 5) (an appropriate combination of the $S(T)$- and $S(P)$-couplings) except the second maximum at the high energy end. The absence of the second maximum in our theory may become more significant. Of course, we can realize the bimodal distribution of electrons by an appropriate admixture with the other coupling types. It should be noticed, however, that if there exists the two-body decay mode $K \rightarrow e^+ \nu$ the resulting electron will have an energy $\sim 246$ Mev. Within the accuracy of the present experimental technique it will be very hard to remove such a contamination. At present it seems to the author that we cannot entirely rule out the possibility that the second maximum at the high energy end is due to the $K_{e2}$ mode.

Thus, it is very likely that a single coupling type of the $KU$-int. ($G_3^{S(A)}$ or $G_3^{P(P)}$-coupling) can describe both the electron and the muon distributions in the $K_{e3}$ and $K_{\mu3}$-
On the Decay Interactions of Strange Particles

119

§ 4. Energy spectra of neutrinos in neutral $K_{e0}(K_{u0})$-decay

As has been noticed in the introduction, the characteristics of the $KU$-int. are that they are more favourable to the emission of high energy neutrinos than the $F$-int. Consequently, it will be the energy distribution of neutrino that decides whether the $F$-int. or the $KU$-int. is participating in the process. Unfortunately, however, the neutrino energy in charged $K_{u0}^-$ and $K_{e0}$-decays cannot be measured experimentally, since there is only one visible secondary particle. Yet recent discoveries$^{11,12,13}$ of the possible decay mode of neutral $K$-particles $K_{e0}^0(K_{u0}^0) \to e^\pm (\mu^\pm) + \nu + \pi^\pm$ may give a direct test of this question. In these processes we can get experimental data in the laboratory system about the energy-momentum of the electron (muon) $(p_0, p)$, that of the pion $(l_0, l)$ and the angle between them, from which the neutrino energy $q_0$ in the rest system of the $K$-meson can be evaluated, i.e.,

$$q_0 = \left[ M^2 - (p_0 + l_0)^2 + (p + l)^2 \right] / (2M). \quad (4 \cdot 1)$$

Thus, we can easily compare theoretical predictions with experiments in spite of the vague information about the momentum or the direction of the incident neutral $K$-meson which decays in flight. In this section we shall deal with this problem.

Some investigations of the $K^0$-events on the basis of the weak $F$-int. have been made by Pais and Treiman$^9$ and also by Furuichi.$^{14}$ Since $K^0$-events are mainly decays in flight, the theoretical predictions about the energy distribution of pions and the angular correlation between the final pion and electron (muon) cannot be compared with experimental data until the direction and the momentum of the incident $K^0$-meson are determined. Thus, the only practical data which are available for a comparison between theory and experiment are the energy distributions of the neutrino, with which we are concerned here. (The energy spectra of electrons (muons) are almost identical with those in charged $K_{e0}(K_{u0})$-decay except a small correction due to the mass difference between charged and neutral pions.) Recent experiments on $\theta$- and $\tau$-mesons strongly suggest that they are particles with spin 0. Moreover, from the fact that $K$-particles, which have various decay modes, have almost the same mass and lifetime, we here consider only the $K$-meson with spin 0, although we cannot exclude the possibility of spin 1 $K$-meson as is seen in the previous section.

The energy distributions of neutrino for the various coupling types of the $KU$-int. are:

$$P_1^{S(A)}(q_0) = \left( G_2^{S(A)2} / 16\pi^2 \right) M^2 q_0^2 \left[ (1/2) \left( E_{\text{max}}^2 - E_{\text{min}}^2 \right) - (W - q_0) (E_{\text{max}} - E_{\text{min}}) \right],$$

$$P_2^{S(A)}(q_0) = \left( G_2^{S(A)2} / 16\pi^2 \right) \left( M^2 / 4 \right) \left[ (W - q_0 - E_{\text{max}}^2) - (W - q_0 - E_{\text{min}}^2)^4 \right],$$

$$P_3^{S(A)}(q_0) = \left( G_2^{S(A)2} / 16\pi^2 \right) M^2 \left[ (1/4) \left( W - E_{\text{max}} \right)^4 - (W - E_{\text{min}}) \right] - (q_0/3) \left( W - E_{\text{max}} \right)^3 - (W - E_{\text{min}})^3, \right]$$
\[ P^{S(P)}(q_0) = \left( G_{S(P)}^2 / 16 \pi^4 \right) M^2 \left\{ - (M^2/4) \left( W-q_0-E_{\text{max}}^2 - (W-q_0-E_{\text{min}}^2 \right) \right. \]
\[ + (m^2 q_0^2/2) \left\{ - (W-q_0-E_{\text{max}}^2) + (W-q_0-E_{\text{min}}^2) \right\} \]
\[ + M q_0 (W-q_0)^2 (E_{\text{max}}^2 - E_{\text{min}}^2) - (4Mq_0/3) (W-q_0) (E_{\text{max}}^3 - E_{\text{min}}^3) \]
\[ + (Mq_0/2) (E_{\text{max}}^4 - E_{\text{min}}^4 \right), \]

where

\[ E_{\text{max}} = \left[ (M-q_0) (W-q_0) \pm q_0 \sqrt{(Q-q_0) (Q'-q_0)} \right] / (M-2q_0), \]
\[ Q = [M^2 - (m+\kappa)^2] / (2M), \quad Q' = [M^2 - (\kappa-m)^2] / (2M). \]

These curves are given in Fig. 4 (assuming \( K^0\)-mass = \( K^\pm\)-mass = 966 \( m_e \)) and, as are expected, have large distributions in high energy regions both for \( K^0\_\mu\)- and \( K^0\_\tau\)-decays. Here we are especially interested in the energy distribution of neutrino in the \( K^0\_\mu\)-decay. In the theory based on the \( F\)-int. the transition matrix elements contain the four-momenta of electrons and neutrinos always in the combination \( p+q \) for every coupling type. Further the electron mass is negligibly small. Owing to these circumstances, the neutrino distribution almost coincide with the electron distribution for any combination of various coupling types of the \( F\)-int. Therefore, if we use the linear combination of \( S(T)\)- and \( S(P)\)-couplings of the \( F\)-int., by which the fittest result to the experimental distribution of electrons in charged \( K^0\_\mu\)-decay can be obtained, the neutrino distribution in the \( K^0\_\mu\)-decay will have its maximum at \( \sim 100 \) Mev and have a large distribution in the region 50 Mev \( \sim 150 \) Mev. In contrast to this, the result for the \( G_{\mu,0}^{S(A)}\)-coupling of the \( K^0\_\mu\)-int. behaves quite differently and has...
a large distribution in the energy region 160 Mev~210 Mev. Thus, the neutrino distribution in the $K_{e3}^0$-decay has a decisive role whether the $KU$-int. or the $F$-int. is participating in these decays.

At present we have few experimental data on the process $K_{e3}^0(K_{\mu3}^0) \to e^\pm (\mu^\pm) + \nu + \pi^\mp$ and fewer data in which both pions and electrons (muons) are identified. We record in Table 2 the experimental data concerning events which are probably $K_{e3}^0$-decays, together with the neutrino energy $q_0$ calculated by (4·1). It seems that the neutrino is likely to be emitted with rather high energy and this tendency is consistent with our predictions. But, in view of poor statistics of the experimental data and much uncertainty in the momentum measurements, we cannot draw any definite conclusions. Further experimental information on the $K_{e3}^0$-decay process is very important and desirable.

Table 2. Data of the probable $K_{e3}^0$-decay

<table>
<thead>
<tr>
<th>event No.</th>
<th>+momentum (Mev/c)</th>
<th>-momentum (Mev/c)</th>
<th>angle (degree)</th>
<th>$q_0$ (Mev)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>224±5</td>
<td>58.5±4</td>
<td>91.5±3</td>
<td>195</td>
</tr>
<tr>
<td>9</td>
<td>241±33</td>
<td>67±20</td>
<td>142±3</td>
<td>163</td>
</tr>
<tr>
<td>15</td>
<td>&gt;150</td>
<td>62</td>
<td>99±3</td>
<td>198*</td>
</tr>
<tr>
<td>59647</td>
<td>409~535</td>
<td>39.5±1.5</td>
<td>83±1</td>
<td>188~196</td>
</tr>
<tr>
<td>69328</td>
<td>11.9±0.9</td>
<td>200±36</td>
<td>46.1</td>
<td>202</td>
</tr>
</tbody>
</table>

* $q_0$ for event 15 is calculated for $p_\mu = 150$ Mev/c.

§ 5. Remarks on the hypothesis of the $KU$-int.

In this paper we have assumed that the $KU$-int. plays an important role in the weak interactions in which the existence of strange particles must be taken into account, and decay events of charged and neutral $K_{e3}$ and $K_{\mu3}$ have been investigated. If, however, our assumption is close to reality, some modifications will be necessary of discussions about the other phenomena, such as the $K_{e3}^0$-decay and the $\beta$-decay of Hyperons. In this section we make some remarks on these problems.

1. Decay of the K-meson into two leptons

Concerning the decay of the K-meson into two leptons we are informed of the decay mode $K_{e3}^0 \to \mu^\pm + \nu$, but the corresponding decay mode $K_{e3}^0 \to e^\pm + \nu$ has not been found.* The situation is quite similar to the well-known $\pi^- \to e^- + \nu$ puzzle. So far the absence of the $\pi^- - e^-$ or $K_{e3}^0$-decay has been interpreted by assuming the interaction among pion (K-meson), neutrino and electron or muon of the following form:

$$\sim \bar{\psi} \gamma_5 \gamma_{\mu} \psi \cdot \partial_{\mu} \phi.$$  \hfill (5·1)

((5·1) can be regarded as the pseudovector interaction among two Fermions and a Boson, or alternatively as the transition matrix element of the Boson decay via baryon loops by

* There are two events which may belong to the $K_{e3}$ mode.\cite{9,16}
the pseudovector coupling of the F-int.\textsuperscript{10)}

In our theory in which the KU-int. is assumed for strange particles, the possible coupling which contributes to the \( K_{u \bar{u}}(K_{d \bar{d}}) \) decay is the vector coupling for scalar \( K \)-meson (pseudovector coupling for pseudoscalar \( K \)-meson). Hence we have

\[
\tau_{K-\mu}/\tau_{K-\nu} = (M^2 - m_e^2)^4/(M^2 - m_{\mu}^2)^4, \tag{5.2}
\]

which is close to unity and is inconsistent with the experiments. This may be a defect of our theory. If, however, we tentatively assume, besides (2.7), the following interaction

\[
\hat{\tau}_{\gamma_{\mu}} \partial_{\nu} \varphi + \hat{\bar{\tau}}_{\gamma_{\mu}} \partial_{\nu} \varphi, \tag{5.3}
\]

which contains an additional derivative of the baryon wave function\* and is symmetric with respect to indices \( \mu \) and \( \nu \), the transition matrix element of the following type is possible for the \( K_{u \bar{u}}(K_{d \bar{d}}) \) decay:

\[
\hat{\tau}_{\gamma_{\mu}} \partial_{\nu} \varphi \times \partial_{\mu} \partial_{\nu} \varphi. \tag{5.4}
\]

This leads to

\[
\tau_{K-\mu}/\tau_{K-\nu} = (m_e^2/m_{\nu}^2) \cdot (M^2 - m_e^2)^4/(M^2 - m_{\mu}^2)^4 \sim 10^{-6}, \tag{5.5}
\]

which is consistent with experimental observations.

The interaction (5.3) will also give rise to \( K_{e \bar{e}} \) and \( K_{e \bar{s}} \) decays. There are, however, some difficulties in treating such an interaction, where the notion of free particles and their mutual interaction becomes somewhat ambiguous. Moreover, as was mentioned in § 3, we cannot distinguish the electrons at the high energy end of the \( K_{e \bar{e}} \) mode from those due to the \( K_{e \bar{s}} \) mode within the accuracy of the present experimental technique, and the relative ratio \( K_{e \bar{e}}/K_{e \bar{s}} \) may be altered in future experiments. Therefore, we merely suggest (5.3) as a tentative assumption and do not consider this problem any further. The problem of the \( K_{e \bar{e}} \) decay must be further investigated both theoretically and experimentally.

2. \( \beta \)-decay of Hyperons

The existence of the KU-int. will bring about the possible \( \beta \)-decay of Hyperons, e.g.,

\[
\Lambda \rightarrow P + e + \nu. \tag{5.6}
\]

It has been pointed out by Furuichi\textsuperscript{14} that the assumption of the primary F-int. also leads to this process. If, however, (5.6) is caused by the F-int. the energy will be equally distributed among electron and neutrino,\textsuperscript{15} and the most probable electron energy is \( \sim E_0/2 \), where \( E_0 \) is the maximum electron energy.\textsuperscript{16} In contrast to this, if the KU-int. is responsible to the process (5.6), the electron receives on the average much less

\* So far we have not met with phenomena in which derivatives of the wave function of heavy particles are required. It is interesting, however, to notice that the very weak interaction between the gravitational and the matter field may contain such a derivative.\textsuperscript{17}
On the Decay Interactions of Strange Particles

than half the maximum energy $E_0$ and the most probable energy will be shifted to $\sim E_0/3$. At present we have only one event which may be a $\beta$-decay of $\Sigma^{16}$ and further experimental investigations are eagerly awaited.

§ 6. Concluding summary

Under the assumption that some universal interaction of a new kind may play an essential role in weak interactions in which particles with strange properties take part, we have analysed the decays of $K$-mesons and Hyperons with lepton secondaries. Our starting points are:

1. Transition matrix elements are Lorentz invariant.
2. The decay of $K$-mesons is caused by the collaboration of the strong and the weak $K\mu$-int. which acts only once in the whole course of the decay process.

In the theory based on the $F$-int., different selections of coupling types are required for the energy spectra of electrons and muons in the $K^\pm$ and $K^0$-decay respectively, while in our theory a single coupling type ($G^{V(A)}_5$- or $G^{P(\phi)}_3$-coupling) gives the results which agree with the experimental data to the same extent as those obtained in the case of the $F$-int. (§ 3). In order to make clear the contrast between the $F$-int. and the $K\mu$-int., we have investigated the neutrino distribution in the neutral $K_{\mu\nu}(K_{\nu\mu})$-decay and have found that the $K\mu$-int. is more favourable to the emission of high energy neutrinos than the $F$-int. Let it be emphasized that the neutrino distribution in the $K^0$-decay gives a crucial test which of the two is responsible to these processes. Though we have very few experiments on the $K^0$-decay, a preliminary investigation on available data seems to be favourable to, at least not inconsistent with, our predictions (§ 4). In the last section the $K^\pm$-decay and the possible $\beta$-decay of Hyperons are briefly discussed.

It is indeed very interesting from the view-point of aesthetics as well as economy of thought to describe all phenomena through the collaboration of the strong and the familiar Fermi interaction. Nevertheless, those phenomena in which strange particles play an active part are, as it were, the new and unknown world and it will not be hard to imagine that there are various strange factors which are unfamiliar to our present knowledge. Therefore it may be promising as well to assume that some new kind of interactions, such as the $K\mu$-int., may play an essential role when we go a step further inside this world.

We have noticed the existence of two classes of phenomena. Practically speaking, however, the border between these two classes is not so clear and there are phenomena for which it is not apparent to which class they belong. For example, if the $\pi - \mu(e)$ decay is caused through the intermediation of the baryon loop, it will be possible that the hyperons as well as nucleons participate in this process. Although the borderland is rather obscure at present, it is an interesting problem to what extent we can reduce it.

Throughout this paper our considerations have been confined to the weak interactions which involve neutrinos. We also know, however, other weak interactions which are not neutrino processes. It still remains to be an open question whether they can be described...
consistently in terms of the $KU$-int.* In view of the results obtained in the present analysis, further investigations into this problem will be of much value and of great importance.

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**References**

14) S. Furuichi, to be published.

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* It may be that the concept of the weak $KU$-int. also has to be extended so as to include four-baryon processes.