for the intervals 150–600 MeV/c and 600–1500 MeV/c are also shown. They are 22±10 mb (6 events) and 19±5 mb (20 events), respectively. The agreement is considered satisfactory particularly in the lower momentum interval. In the upper interval the calculated results are less certain since they are derived from a neutron-proton potential considered unreliable at these energies.

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K_{l4} Decays and the Structure of the $\Delta S=1$ Currents

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It is shown that the search for various modes of K_{l4} decays may give valuable information regarding the structure of the strangeness-nonconserving currents. At the same time such a search provides a severe test for a class of theories of weak interactions, in which all charged currents are coupled to the leptonic current and satisfy the abstract properties of Gürsey's model.

RECENT experiments indicate the existence of isotopic spin $I=\frac{3}{2}$ vector currents.[1–4] If the assumptions are made that (i) CP invariance holds in the K_{l3} decays and (ii) the form factors describing these processes depend weakly on the pion energy, the combined data of references 1 and 3 support also the existence of $I=\frac{1}{2}$ vector currents.[5,6] It is also important to note that the conclusions of these experiments are in conflict with the rigorous predictions of partially conserved vector currents constructed on the basis of second rank simple Lie algebras, i.e., those simple algebras which allow for just two additive quantum numbers for the strong interactions (SU_3, $Sp[2]$, and G_2).[7,8]

A question which naturally arises at this stage is whether or not axial vector $I=\frac{3}{2}$ currents exist in the weak interactions. Certainly such a question is important on purely phenomenological grounds. There are, however, some specific theoretical arguments which motivate such a quest, which will be briefly discussed.

Gürsey has shown[9] that it is possible to construct a theory of strong interactions invariant under an eight-dimensional orthogonal group of transformations $[O_8]$, which allows for partially conserved $\Delta S=0$ and $\Delta S=1$ vector and axial vector currents. The currents of this theory possess the following properties: (a) They are conserved in the limit of vanishing meson masses, and (b) both $I=\frac{1}{2}$ and $I=\frac{3}{2}$ currents are allowed in the vector interaction, but only $I=\frac{1}{2}$ currents are present in the axial vector part. Independently of this model for the strong interactions, Gürsey has also emphasized that parity mixtures are not allowed for the $I=\frac{3}{2}$ currents if (a) holds and certain assumptions are made concerning the nature of the existing mesons and the

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[1] R. P. Ely, W. M. Powell, H. White *et al.*, Phys. Rev. Letters 8, 132 (1962).

[2] A. Barbaro-Galtieri, W. H. Barkas, H. H. Heckman *et al.*, Phys. Rev. Letters 9, 26 (1962).

[3] G. Alexander, S. P. Almeida, and F. S. Crawford, Jr., Phys. Rev. Letters 9, 69 (1962).

[4] Because many parities are relative, we adopt the convention that the K meson has negative parity. With this convention, the currents contributing to the K_{l2} and K_{l3} decays behave as axial vectors and vectors, respectively.

[5] The relevant formulas for the isospin analysis of K_{l3} decays are given by R. E. Behrends and A. Sirlin, Phys. Rev. Letters 8, 221 (1962) and lectures at the Second International School of Physics, University of Bergen (to be published).

[6] Assumption (ii) is partially supported by recent experiments. See J. L. Brown *et al.*, Phys. Rev. Letters 8, 450 (1962).

[7] A discussion of this problem and of its implications for the strong interactions was given in the first paper of reference 5. In the case of the G_2 algebra, the prediction of reference 5 is exact to first order in the weak coupling constant and to zero order in α, subject to two qualifications: (a) the assumed CP invariance of the K_{l3} decays and (b) the neglect of possible nonlocal effects of the weak interactions in the K_{l3} decays.

[8] It is interesting to note that, from the data of reference 3, one of the two possible predictions of conservation under the G_2 algebra gives $M_1/M_2=-(2.3_{-0.1}{}^{+0.2})$, where M_1 and M_2 are the matrix elements for $K_1{}^0\to\pi^-+e^++\nu$ and $K_2{}^0\to\pi^-+e^++\nu$. This number is compatible with the measured time dependence of the total decay rate of K^0 into the channels $\pi^-+e^++\nu$ and $\pi^++e^-+\bar{\nu}$, but is in conflict with the sign of the charge asymmetry (see reference 1).

[9] F. Gürsey, Ann. Phys. (N. Y.) 12, 91 (1961).

structure of the meson contribution to the currents. Because of the experimental indications of the existence of both $I=\frac{1}{2}$ and $I=\frac{3}{2}$ vector currents and the apparent failure of the assumption of conservation under the second rank algebras, it is particularly interesting at the present time to consider a class of theories of weak interactions in which all charged currents ($I=1$, $\frac{1}{2}$, and $\frac{3}{2}$) are coupled to leptons and satisfy the properties (a) and (b). Clearly, the experimental determination of the presence or absence of the $I=\frac{3}{2}$ axial vector currents constitutes a crucial test for such theories.[10]

In what follows it will be shown that information regarding the possible existence or absence of these currents can be obtained by searching for the various charged modes of K_{l4} decays. More specifically, if axial vector currents with $I>\frac{1}{2}$ are absent, the rate for $K^+\to\pi^++\pi^++e^-+\bar{\nu}$ should be several orders of magnitude smaller than the rate for $K^+\to\pi^++\pi^-+e^++\nu$ or $K^+\to\pi^0+\pi^0+e^++\nu$. To show this, let us first note that the $\Delta S=1$ axial vector currents, being pure $I=\frac{1}{2}$, cannot contribute to $K^+\to\pi^++\pi^++e^-+\bar{\nu}$. On the other hand, the matrix element of the vector current $\langle\pi^+\pi^+|S_\mu^{(V)}|K^+\rangle$ must transform as a pseudovector under Lorentz transformations. Calling $\mathbf{k}$, $\mathbf{p}_1$, and $\mathbf{p}_2$ the four-momenta of the K meson and the two pions, respectively, defining $\mathbf{p}=\mathbf{p}_1+\mathbf{p}_2$, $\mathbf{q}=\mathbf{p}_1-\mathbf{p}_2$, and remembering that the matrix element must be symmetric under the interchange of the pion momenta, it is seen that the general form for this matrix element is

$$\langle\pi^+\pi^+|S_\mu^{(V)}|K^+\rangle=[i(\mathbf{k}\cdot\mathbf{q})/M^5]f\epsilon_{\mu\lambda\rho\sigma}p_\lambda q_\rho k_\sigma, \quad (1)$$

where f is a scalar function of the invariants p^2, $(\mathbf{p}\cdot\mathbf{k})$ and an even function of $(\mathbf{k}\cdot\mathbf{q})$. The quantity M stands for a mass characteristic of the dominant intermediate states contributing to $K^+\to\pi^++\pi^++e^-+\bar{\nu}$. Because the interaction is assumed to be pure vector, such states must be $J=1^-$ or $J=0^+$. The $J=0^+$ cannot be reached, however, from the $(K^+\pi^-\pi^-)$ system. Thus, the intermediate states must have $J=1^-$, $S=1$, and $I=\frac{3}{2}$ or $\frac{5}{2}$. The lowest mass state with such quantum numbers is the $(K^0\pi^-)$ system in a p state. For this reason, it is natural to consider that $M\geqslant m_K+m_\pi$. Neglecting the dependence of f on p^2, $(\mathbf{k}\cdot\mathbf{p})$, and $(\mathbf{k},\mathbf{q})$,[11] the following result is obtained on the basis of Eq. (1) for the total decay rate ω_{++} of $K^+\to\pi^++\pi^++e^-+\bar{\nu}$:

$$\omega_{++}=1.3\times10^{-7}|f|^2m_K^{15}/\pi^5\times2^{10}\times360M^{10}. \quad (2)$$

On the other hand, both A and V interactions contribute to $K^+\to\pi^++\pi^-+e^++\nu$ and $K^+\to\pi^0+\pi^0+e^++\nu$. In this case, the most general form for the matrix element is

$$\langle\pi_+\pi_-|S_\mu^{(V)}+S_\mu^{(A)}|K^+\rangle=(1/M')[g_1p_\mu+g_2q_\mu+g_3l_\mu+(ig_4/M'^2)\epsilon_{\mu\lambda\rho\sigma}p_\lambda q_\rho k_\sigma], \quad (3)$$

where l_μ stands for the sum of the lepton momenta, the g_i are form factors, and M' is a mass characteristic of the intermediate state. Regarding g_1 and g_2 as constants and neglecting the small contributions of g_3 and g_4, the rate ω_{+-} for $K^+\to\pi^++\pi^-+e^++\nu$ has been calculated.[12–14] Dividing Eq. (2) by Eq. (34) of reference 13, the following result is obtained:

$$\frac{\omega_{++}}{\omega_{+-}}=4.4\times10^{-6}\frac{|f|^2}{|g_1|^2+\frac{1}{10}|g_2|^2}\frac{m_K^8M'^2}{M^{10}}. \quad (4)$$

Inserting $M'\sim M\geqslant m_K+m_\pi\sim m_K$, it is clear that ω_{++} should be several orders of magnitude smaller than ω_{+-} for any reasonable values of $|f|^2/|g_1|^2$, provided that A currents with $I\geqslant\frac{3}{2}$ do not exist.[15] In such a case we would face a rather amusing situation, i.e., a violation of the rule $\Delta Q=\Delta S$ in the K_{l3} and hyperon leptonic decays and the ***apparent*** validity of this rule in the K_{l4} decays. On the other hand, if ω_{++} should be of the same order of magnitude as ω_{+-}, strong evidence would be available for the existence of A currents with $I\geqslant\frac{3}{2}$.

The decay probabilities for $K^+\to\pi^++\pi^-+e^++\nu$ and $K^+\to\pi^0+\pi^0+e^++\nu$ have been roughly estimated in references 12 and 14 to be about 10^3 times smaller than the rate for K_{l3} decays. If this is the case, it should be possible to find out whether ω_{++} is comparable to ω_{+-} or ω_{00} in the near future.

An alternative method is to study the asymmetry of the leptons in $\Sigma^+\to n+l^++\nu$ with respect to the spin of the Σ^+ hyperon. Unfortunately, the possible existence of induced terms may considerably change the asymmetry from what is expected for "bare" interactions,[16] so that the interpretation of such experiment would be, indeed, very difficult.

From the above discussion, it is clear that the search for the various charged modes of K_{l4} decays may shed considerable light on the isospin structure of the weak interactions.

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[10] In his original work, Gürsey did not couple the $I=\frac{3}{2}$ currents to the leptons. Thus, the model for the weak interactions given in reference 9 is already in conflict with references 1–3. In contrast to the case of reference 9, we have in mind a class of theories of weak interactions in which all the charged currents ($I=1$, $\frac{1}{2}$, $\frac{3}{2}$) are coupled to the leptons. See R. E. Behrends and A. Sirlin, Phys. Rev. **121**, 324 (1961), Sec. I.

[11] Note that, for $f=cte$, the two pions are in a relative d state, as can be checked by writing Eq. (1) in their c.m. system.

[12] K. Oneda and S. Chadan, Phys. Rev. Letters **3**, 292 (1959).

[13] L. B. Okun and E. P. Shabalin, J. Exptl. Theoret. Phys. (U.S.S.R.) **37**, 1775 (1959) [translation: Soviet Phys.—JETP **10**, 1252 (1960)].

[14] E. P. Shabalin, J. Exptl. Theoret. Phys. (U.S.S.R.) **39**, 345 (1960) [translation: Soviet Phys.—JETP **12**, 245 (1961)].

[15] Even if we set $M\sim M'\sim m_K$, it would be necessary that $|f|^2/|g_1|^2$ assume an extraordinarily large value ($\sim10^5$) in order that $\omega_{++}/\omega_{+-}\sim1$ in the absence of A currents with $I\geqslant\frac{3}{2}$.

[16] The relevant formulas are given by D. R. Harrington, Phys. Rev. **120**, 1482 (1960).