R, and is

$$k_F = 1.01\times10^8 \text{ cm}^{-1}, \qquad (5)$$

which yields a value 0.41 for the 4s conduction electron/atom ratio. The appreciable width of the bell-shaped term in (4) is surprising, and may possibly be attributed to the nonsphericity of the conduction-electron Fermi surface or to inaccuracies of the underlying theoretical model, employed in the analysis. A number of other functional forms for $\chi(q)$ were tried. We are convinced that the essential features of the solution presented here are implied by the data.

A striking conclusion that must be drawn from the form of the derived $\chi(q)$ is that indirect exchange interactions in Fe via the 4s conduction band are strongly antiferromagnetic. (This feature is actually directly apparent from the ΔH data for nearest and next-nearest neighbors, which, being negative, imply a 4s polarization opposite to that of the central atom. It can be established quantitatively by employing Eq. (9) of reference 3.) The origin of ferromagnetism in Fe must be sought elsewhere. A promising solution to this puzzle has been found and will be presented later.

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SEARCH FOR NEUTRAL LEPTONIC CURRENTS IN K^+ DECAY*

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A basic assumption of most present models of the weak interaction is that primitive neutral leptonic currents, to first order in the weak coupling constant, do not exist.[1] However, some models propose the existence of neutral nonleptonic currents in order to explain the $|\Delta T| = \frac{1}{2}$ rule.[2] Recently it has been suggested that primitive neutral leptonic currents of strength comparable to that of charged currents might exist, but some reactions where they would appear could be inhibited by selection rules among the strongly interacting particles.[3] Even if primitive neutral currents do not exist, the combined effects of weak and electromagnetic interactions can cause induced neutral currents which may be observable.[4,5]

In order to look for evidence of neutral currents in strangeness-changing interactions, the possible decay mode

$$K^+ \to \pi^+ + e^+ + e^- \qquad (1)$$

has been searched for in a sample of 1.7×10^6 stopped-K^+ decays. The K^+ mesons were stopped in the Lawrence Radiation Laboratory 30-inch heavy-liquid chamber filled with C_3F_8. No unambiguous events have been found corresponding to decay mode (1).

The detection procedure consisted of initially scanning for three-track decays that were not examples of the ordinary τ decay of the K^+. About two thirds of the film was scanned twice. Each event was then carefully looked at again on the scanning table and was classified in one of the following three categories: (a) ordinary Dalitz pair with obvious missing momentum; (b) apparent momentum-conserving event; (c) electron pairs which converted very near the K^+ decay.

The events in categories (a) and (b) were used to compute the absolute scanning efficiency from the number of Dalitz decays expected. About

6000 ordinary Dalitz-pair events were found, giving a scanning efficiency of 84%. In category (b) only events with an angle between the electron and positron of greater than 10° were accepted as candidates for mode (1). This reduces the background considerably and does not significantly reduce the detection efficiency. The remaining events were measured and constrained to the hypothesis of decay mode (1). The electron energies were corrected for bremsstrahlung energy loss using the Behr-Mittner method. Because of the inability to measure any momentum to a precision of better than 20%, the events were tested for decay mode (1) using mainly a one-constraint fit, which does not include the measured momenta. Since this fit depends only on angle measurements, it also contains a good coplanarity test ant it is expected to be quite reliable. The χ^2(1C) distribution for all events with $\chi^2 < 50$ is shown in Fig. 1.

The most serious background for decay mode (1) comes from

$$K^+ \to \pi^+ + \pi^0 \to \pi^+ + e^+ + e^- + \gamma, \qquad (2)$$

where the γ ray does not materialize and comes off at the right center-of-momentum angles to make the charged particles nearly coplanar. The configurations of mode (2) that fit the hypothesis for mode (1) always have missing γ-ray momentum in the same direction as the positive pion momentum; this leads to a fitted pion momentum for this hypothesis that is greater than or equal to the unique momentum of decay mode (2): namely, 205 MeV/c. Modes (1) and (2) can be separated by selecting events with fitted momentum of less than 205 MeV/c as examples of (1).

Unfortunately there are also other three-body decay K^+ modes with Dalitz pairs that can fake mode (1) and give a fitted momentum below 205 Mev/c. In general, there is no way to separate these events from mode (1) unless the assumed pion stops in the chamber, thus allowing an accurate momentum measurement by range. The number of such background events is expected to be at least an order of magnitude below that of Reaction (2).

Figure 2 shows a histogram of all events with $\chi^2(1C) \le 10$ plotted as a function of the pion momentum obtained from the 1C fit. For the events with $P_\pi > 205$ MeV/c there are five that have stopping pions in the chamber with the range expected for decay mode (2); using geometrical loss for this range we expect 21 examples of decay mode (2) compared to 26 events above 205 MeV/c. Thus all events above 205 MeV/c are consistent with mode (2). The important characteristics of the three events with pion momentum below 205 MeV/c are summarized in Table I. The first two events cannot be examples of (1) and are most likely examples of

$$K^+ \to \pi^0 + \begin{pmatrix}\mu^+\\ e^+\end{pmatrix} + \nu \to e^+ + e^- + \gamma + \begin{pmatrix}\mu^+\\ e^+\end{pmatrix} + \nu. \qquad (3)$$

The third event has a large invariant mass and is unlikely to be an example of (2) or (3). We expect 0.2 events of type (2) with an e^+-e^- invariant mass between 115 and 125 MeV and a negligible number of type (3).[6] However, because of the large uncertainty in invariant mass of this event we are unable to conclude that it is an unambiguous event and shall consider it as an upper limit. Assuming that decay mode (1) comes about

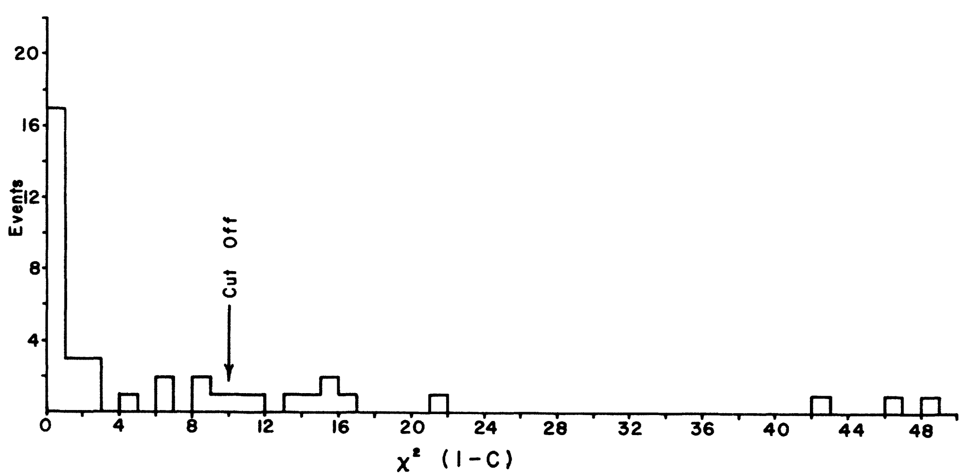

FIG. 1. χ^2(1C) distribution for events that have the configuration expected for $K^+ \to \pi^+ + e^+ + e^-$.

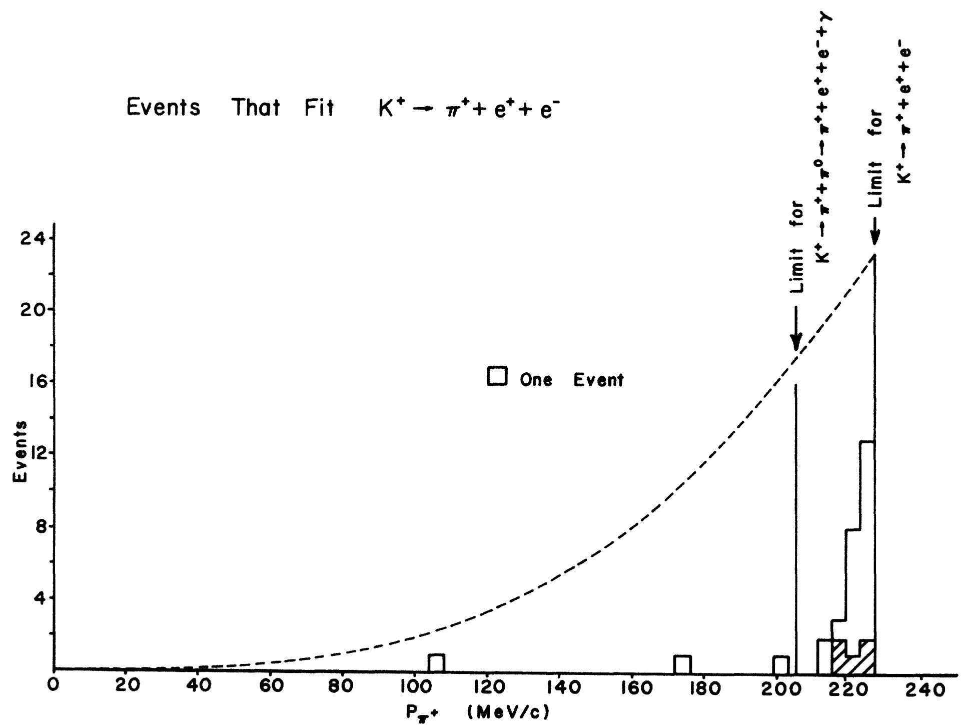

FIG. 2. The pion-momentum spectrum [as deduced from all events with $\chi^2(1C) < 10$] is shown. The dashed line represents "the expected spectrum" for induced or primitive neutral currents. The cross-hatched events are pions that stopped in the chamber indicating that they are examples of decay mode (2).

through primitive neutral currents, it is reasonable to expect that the pion spectrum should be that expected for the ordinary K_{e3}. The same spectrum is theoretically predicted for the induced neutral current contribution to decay (1).[4] On the basis of this spectrum for $P_\pi < 205$ MeV/c, the total detection efficiency is calculated to be 55%, which gives an effective sample size of 9.4×10^5 stopped-K^+ decays. An invariant phase-space pion spectrum leads to a larger detection efficiency. Since one possible event was found, the branching ratio is

$$\frac{\Gamma(\pi ee)}{\Gamma(\text{all})} \leq \frac{1}{9.4\times10^5} = 1.1\times10^{-6};$$

the 90% confidence level is 2.45×10^{-6}. The 90% confidence level for the upper limit[7] of the ratio of primitive neutral leptonic current to charged leptonic current coupling constants is

$$|g_{e\bar{e}}|^2 \leq 2.5\times10^{-5}|g_{e\bar{\nu}}|^2.$$

It has been shown in a model for decay mode (1) through induced neutral currents that the branching ratio is proportional to $f_{K\pi}$, the weak K-π coupling constant.[5] To the extent that this model describes the actual decay mode (1), we can put a conservative limit on $f_{K\pi}$:

$$f_{K\pi}(-m_K^{\,2}) \leq 7\times10^{-8} m_K^{\,2}.$$

Biswas and Bose[8] pointed out that the K_1-K_2 mass difference demands a rate for decay mode (1) larger than the limit for this rate found in this experiment, if the dominant contribution to K_1-K_2 mass difference comes from the π^0 and η^0 pole. The value of $f_{K\pi}^{\;2}$ required to give a reasonable value of the K_1-K_2 mass difference is 40 times larger than the 90% confidence level found in this experiment.

Table I. Characteristics of events with fitted pion momentum of less than 205 MeV/c. χ^2 is for the 1C fit; $P\pi^+$ is the momentum from the same fit; $P\pi_\gamma$ is the lower limit on the momentum from the observed range of the π^+ in the chamber.

Event	$P\pi^+$	$P\pi_\gamma^{\,+}$	$M_{e^+-e^-}$* (MeV)	χ^2(1C)
146 389	106 ± 3	115.8	40 ± 20	0.92
116 859	174 ± 3	180	69 ± 33	0.60
187 088	201 ± 3.7	189.2	120 ± 55	0.77

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BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

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It is of interest to inquire whether gauge vector mesons acquire mass through interaction[1]; by a gauge vector meson we mean a Yang-Mills field[2] associated with the extension of a Lie group from global to local symmetry. The importance of this problem resides in the possibility that strong-interaction physics originates from massive gauge fields related to a system of conserved currents.[3] In this note, we shall show that in certain cases vector mesons do indeed acquire mass when the vacuum is degenerate with respect to a compact Lie group.

Theories with degenerate vacuum (broken symmetry) have been the subject of intensive study since their inception by Nambu.[4-6] A characteristic feature of such theories is the possible existence of zero-mass bosons which tend to restore the symmetry.[7,8] We shall show that it is precisely these singularities which maintain the gauge invariance of the theory, despite the fact that the vector meson acquires mass.

We shall first treat the case where the original fields are a set of bosons φ_A which transform as a basis for a representation of a compact Lie group. This example should be considered as a rather general phenomenological model. As such, we shall not study the particular mechanism by which the symmetry is broken but simply assume that such a mechanism exists. A calculation performed in lowest order perturbation theory indicates that those vector mesons which are coupled to currents that "rotate" the original vacuum are the ones which acquire mass [see Eq. (6)].

We shall then examine a particular model based on chirality invariance which may have a more fundamental significance. Here we begin with a chirality-invariant Lagrangian and introduce both vector and pseudovector gauge fields, thereby guaranteeing invariance under both local phase and local γ_5-phase transformations. In this model the gauge fields themselves may break the γ_5 invariance leading to a mass for the original Fermi field. We shall show in this case that the pseudovector field acquires mass.

In the last paragraph we sketch a simple argument which renders these results reasonable.

(1) Lest the simplicity of the argument be shrouded in a cloud of indices, we first consider a one-parameter Abelian group, representing, for example, the phase transformation of a charged boson; we then present the generalization to an arbitrary compact Lie group.

The interaction between the φ and the A_μ fields is

$$H_{\rm int} = ieA_\mu \varphi^* \overleftrightarrow{\partial}_\mu \varphi - e^2 \varphi^* \varphi A_\mu A_\mu, \tag{1}$$

where $\varphi = (\varphi_1 + i\varphi_2)/\sqrt{2}$. We shall break the symmetry by fixing $\langle\varphi\rangle \neq 0$ in the vacuum, with the phase chosen for convenience such that $\langle\varphi\rangle = \langle\varphi^*\rangle = \langle\varphi_1\rangle/\sqrt{2}$.

We shall assume that the application of the