$t^{-1}$ factors in Eq. (14)].

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# EXPERIMENTAL EVIDENCE AGAINST THE EXISTENCE OF STRANGE LEPTONS*

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Arguments based on experimental evidence are presented against the existence of strange leptons, as recently suggested by Weiner.

In a recent paper, Weiner has made the interesting suggestion that strange leptons exist and that strangeness is thereby conserved in semileptonic decays of strange particles.[1] The selection rules in semileptonic decays are deduced from this hypothesis without the necessity of invoking the "absence of neutral leptonic currents" and the "$\Delta S = \Delta Q$ rule." Weiner suggests that in addition to the usual leptons there exist strange leptons according to three possibilities:

(i) There exist neutral strange leptons, $\nu^S$ and $\bar{\nu}^S$, with strangeness $-1$ and $+1$, respectively.

(ii) There exist charged strange leptons $\mu^{+S}$, $e^{+S}$ and $\mu^{-S}, e^{-S}$ with strangeness +1 and $-1$, respectively.

(iii) There exist both the charged and neutral strange leptons listed above.

We present here direct experimental evidence againt possibility (ii) by showing that $\mu^-$'s from the decay $K_L^0 \to \pi^+ + \mu^- + \bar{\nu}$ undergo nuclear capture with the same rate as $\mu^-$'s from $\pi^-$ decays. We also discuss evidence against the other two possibilities.

For purposes of reference we shall designate muons from $K_{\mu 3}^0$ decay as $\mu_K^\pm$ and those from $\pi^\pm$ decay as $\mu_\pi^\pm$. If Weiner's second possibility is correct, strangeness is conserved in $K_{\mu 3}^0$ decay with

$$K_L^0 \to \pi^\pm + \mu_K^{\mp S} + \bar{\nu}(\nu).$$

The mean life for $\mu_\pi^-$ in carbon is shorter than that for $\mu_\pi^+$ because some of the $\mu_\pi^-$ undergo nuclear capture in the reaction

$$\mu_\pi^- + p \to n + \nu.$$

If strange neutrinos do not exist this process

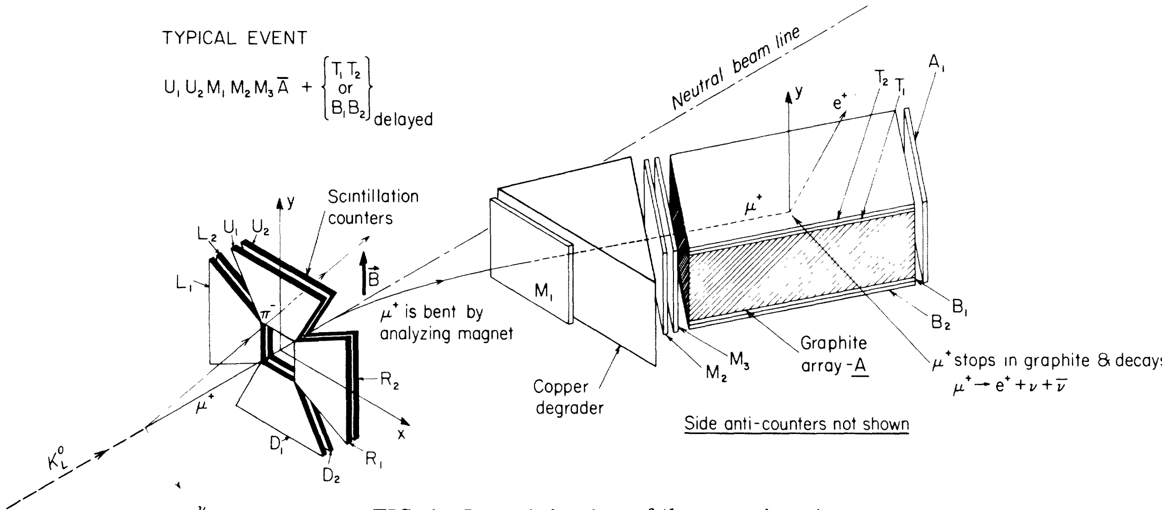


FIG. 1. Isometric view of the experiment.

cannot occur for strange muons, so $\mu^{+S}$ and $\mu^{-S}$ would have identical mean lives in carbon.

We have measured the mean lives of $\mu_K^{\pm}$ (from $K_{\mu 3}^0$ decay) which were brought to rest in carbon. The mean lives for both were found to be equal to those for $\mu_\pi^{\pm}$ stopped in carbon.

The data for the muon lifetimes were collected in an experiment to study the polarization of the muons from $K_{\mu 3}^0$ decay.[2] An isometric view of the experiment is shown in Fig. 1. A neutral beam was taken from a target in the external proton beam of the Bevatron. Some of the $K_L^0$ mesons in the beam decayed in the decay volume immediately upstream of our apparatus. Muons of either sign were selected by a bending magnet and separated from hadrons and electrons by passing them through about five collision lengths of copper. Some of the muons were brought to rest in graphite, and the electrons from the muon decay were then detected in scintillation counters above and below the graphite ($T_1T_2$ and $B_1B_2$ in Fig. 1). The pion from the $K_L^0$ decay was also detected in scintillation counter $L$, $R$, $U$, or $D$. The experiment is described in greater detail in an earlier paper.[2] The time delay between the stopping of the muon and the detection of the decay electron was measured with a time-to-amplitude converter, and the data were accumulated in a pulse height analyzer. The bending magnet was reversed periodically so that muons of both signs could be studied.

The most probable mean life was found by maximizing the two-parameter probability function

$$p(\lambda, b) = \prod_{i=1}^{N} \left[ \frac{\lambda \exp(i\lambda t_i) + b}{\int_{T_1}^{T_2} (\lambda e^{-\lambda t} + b) dt} \right],$$

where $\lambda^{-1} = \tau$ is the mean life, $b$ is the background, $t_i$ is the decay time of the $i$th event, $N$ is the total number of events, and $T_1$ and $T_2$ bound the time of observation. The time independence of $b$ was checked by monitoring $b$ at widely spaced intervals of time.

Figure 2 gives the measured time distribution and the best-fit curve. The results for the mean lives are

$$\tau_{\mu_K^+} = 2.192 \pm 0.012 \ \mu\text{sec}$$

and

$$\tau_{\mu_K^-} = 2.000 \pm 0.032 \ \mu\text{sec}.$$

The quoted errors are only the statistical errors. The systematic errors are <0.04 $\mu$sec. The ratio of the two mean lives (in carbon) is

$$\tau_{\mu_K^-}/\tau_{\mu_K^+} = 0.912 \pm 0.015.$$

The systematic error is expected to be small for the ratio of the mean lives so that the quoted error is the total error for the measurement. A check for systematic errors in the ratio was made by calculating the ratio of the mean lives for various subsamples of the data. The ratios from these subsamples were consistent with each other and with the ratio from the total sample. Our result agrees with the ratio of the mean lives of muons (stopped in carbon) from pion decay,[3]

$$\tau_{\mu_\pi^-}/\tau_{\mu_\pi^+} = 0.9209 \pm 0.0015,$$

$$\tau_{\mu_\pi^+} = 2.2000 \pm 0.0015 \ \mu\text{sec},$$

$$\tau_{\mu_\pi^-} = 2.026 \pm 0.003 \ \mu\text{sec}.$$

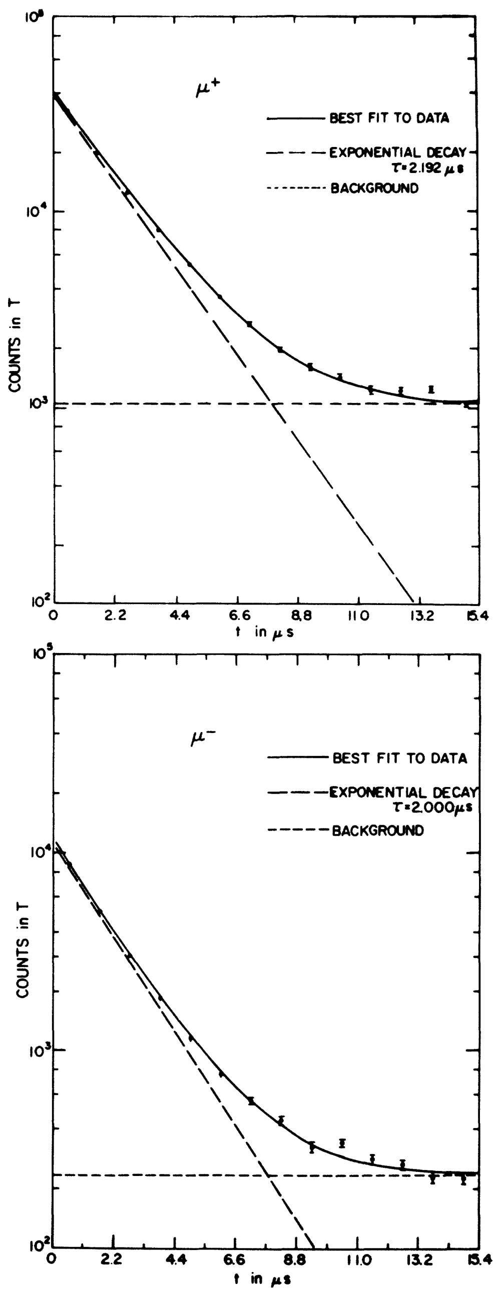


FIG. 2. Time distribution of the decay rate of positive and negative muons stopped in graphite.

From this we conclude that the muon capture rate of $\mu_K^-$ is the same as for $\mu_\pi^-$ in contradiction to the prediction of possibility (ii) of Weiner's theory. Possibility (iii) remains provided the rate for $\mu^{-S}+p \rightarrow n+\nu^S$ is similar to that for $\mu^- + p \rightarrow n + \nu$ or provided that most of the $\mu^-$ from $K_{\mu 3}{}^0$ decay are nonstrange. The latter alternative merges with Weiner's possibility (i), about which we can draw no conclusions.

An argument against possibility (i) is the apparent absence of the decay mode $K^+ \rightarrow \pi^+ + \bar{\nu}^S + \bar{\nu}$ which conserves strangeness and lepton number according to the assignments made by Weiner. Without special assumptions to suppress it the rate for this decay should be approximately equal to that for $K^+ \rightarrow \pi^0 + e^+ + \nu$. The experimental upper limit for the former mode is $(K^+ \rightarrow \pi^+ + \bar{\nu}^S + \bar{\nu})/(K^+ \rightarrow \pi^0 + e^+ + \nu) \lesssim \frac{1}{10}$.[4]

Beall[5] has presented an argument against possibility (iii). This is the possibility of the reaction $e^- \rightarrow e^{-S} + \nu + \bar{\nu}^S$ which would allow electrons in high-lying atomic states to decay to a lower-lying state. The result would be that all atoms with $Z \gtrsim 30$ would have four electrons in the $S$ shell. Another argument against the existence of strange charged leptons, as Weiner himself points out, is that it should be possible to pair produce $\mu^{\pm S}$ and $e^{\pm S}$. This would cause a disagreement by a factor of 2 between the experimental results for pair production and the Bethe-Heitler formula. Experimentally, however, the pair production cross sections agree with theory to about 10%.[6]

Another difficulty with possibility (ii) is that it allows the decay $K^+ \rightarrow \pi^- + l^{+S} + l^+$ which conserves strangeness and lepton number.[7] This decay would be allowed if the $\Delta S = \Delta Q$ rule and the absence of neutral leptonic currents are not specifically invoked. A reasonable upper limit on the branching ratio for $K^+ \rightarrow \pi^- + \mu^{+S} + \mu^+$ is probably that for $K^+ \rightarrow \mu^- + \mu^+ + \pi^+$ which is less than $2.4 \times 10^{-6}$.[8]

Thus we conclude there is strong evidence against all three possibilities proposed by Weiner, though the possibility that strange neutrinos exist cannot be ruled out completely.

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# EXPERIMENTAL DETERMINATION OF Re$\xi$ FROM $K_{\mu 3}{}^0$ DECAY*

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From measurements of the polarization of muons from $K_{\mu 3}{}^0$ decay, we have found the average longitudinal component to be $0.88 \pm 0.25$, and the average component in the plane of decay but perpendicular to the muon momentum to be $0.369 \pm 0.036$. From these we determined $\mathrm{Re}\xi = -1.75_{-0.2}^{+0.5}$, assuming constant form factors. The behavior of $\mathrm{Re}\xi(0)$ with varying form factors is discussed.

The three components of polarization of the muon from the decay $K_L{}^0 + \pi^- + \mu^+ + \nu$ were measured at the Bevatron. The component $P_T$ transverse to the plane of decay has been discussed elsewhere.[1] It provides a measure of the violation of time-reversal invariance in $K_{\mu 3}{}^0$ decay and was found to be consistent with zero. Therefore, we take Im$\xi$ to be zero; so $\mathrm{Re}\xi \equiv \xi$. The nonzero components of polarization are $P_L$, the longitudinal component, and $P_P$, the component that is in the plane of decay, but perpendicular to $P_L$. The longitudinal component $P_L$ is along $\vec{p}_\mu$, the momentum of the muon, and the perpendicular component $P_P$ is parallel to $\vec{p}_\mu \times (\vec{p}_\mu \times \vec{p}_\pi)$, where $\vec{p}_\pi$ is the momentum of the pion.

The components of muon polarization are expressed relative to directions of momenta in either the $K_L{}^0$ rest system or the laboratory system. Cabibbo and Maksymowicz have given expressions for both cases.[2] The polarization is expressed in terms of $\xi(q^2)$, the ratio of the two form factors $f_-(q^2)$ and $f_+(q^2)$, where $q^2$ is the absolute value of the square of the four-momentum transferred to the di-lepton system, i.e., $q^2 = M_K{}^2 + m_\pi{}^2 - 2M_K E_\pi$. Assuming that the form factors are slowly varying, their $q^2$ dependence can be taken as

$$f_-(q^2) = f_-(0)[1 + \lambda_-(q^2/m_\pi{}^2)] \tag{1}$$

and

$$f_+(q^2) = f_+(0)[1 + \lambda_+(q^2/m_\pi{}^2)]. \tag{2}$$

Therefore,

$$\xi(q^2) = f_-(q^2)/f_+(q^2)$$

$$= \xi(0)[1 + \lambda_-(q^2/m_\pi{}^2)]/[1 + \lambda_+(q^2/m_\pi{}^2)], \tag{3}$$

where $f_-(0)$, $f_+(0)$, $\xi(0)$, $\lambda_-$, and $\lambda_+$ are constants. The goal of the experiment was to obtain information about these constants by measuring $P_L$ and $P_P$.

An isometric view of the experiment is shown in Fig. 1. Conventional scintillation counter techniques were used. $K_L{}^0$ mesons decayed in flight upstream from counters $U_1$ and $D_1$. The neutral beam had a flux of $\sim 5 \times 10^5$ $K$'s per pulse of $5 \times 10^{11}$ protons in the external beam of the bevatron. The $K_L{}^0$ momentum ranged approximately from 1 to 4 GeV/$c$.

Negative pions from accepted events passed