ON STRANGE LEPTONS*

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We present arguments that militate against Weiner's recent proposal that neutral leptonic currents exist, and against the variants of his proposal of strange leptons that involve charged strange leptons. A modified scheme with the addition of only the strange neutrinos, or of only one of them and its antiparticle, is in agreement with the predictions of the Cabibbo theory with the exception of neutrino-induced reactions.

Weiner has proposed a weak-interaction scheme wherein both normal and strange leptons exist and wherein strangeness is conserved in leptonic and semileptonic (although not nonleptonic) weak processes.[1] In this way neutral leptonic currents may be allowed in weak-interaction theory, but are not observed in such likely reactions as $K^+ \to \pi^+ + l^+ + l^-$ because of ordinary conservation laws. A possible set of quantum numbers is given in Weiner's paper and is reproduced here as Table I.[2] He has given three possible strange variants of the scheme, according to whether the strange neutrinos listed in the table, the strange charged leptons, or both exist.

We give the following argument against the last of the three variants:

If strange and normal electrons with masses equal to within a few percent and strange and normal neutrinos were all to exist, with the quantum numbers as assigned in Table I assumed to be conserved, then a normal electron in a high atomic state could convert to a strange electron in a lower state[3] via the reaction

$$e^- \to e^{-s} + \nu + \bar{\nu}^s. \qquad (1)$$

This reaction would occur in first order if the weak interaction contained either the coupling of two neutral, strangeness-changing currents, or of two $\Delta S = 0$, $\Delta Q = 1$ currents, or of two $\Delta S/\Delta Q = 1$ currents. We would expect at least one of such couplings if any sort of "universal" current-current theory were to pertain.

Table I. Quantum number assignments. Note: μ-e universality is assumed.

Particle	Lepton number	Strangeness
ν	1	0
$\bar{\nu}$	−1	0
l^+	−1	0
l^-	1	0
ν^s	−1	−1
$\bar{\nu}^s$	1	1
l^{+s}	1	1
l^{-s}	−1	−1

In order to estimate the rate for process (1), we assume a definite interaction Hamiltonian density containing the term[4]

$$\mathcal{H}_I = -(G/\sqrt{2})[\bar{\psi}_{es}\gamma_\mu(1-\gamma_5)\psi_{\nu s}] \times [\bar{\psi}_\nu\gamma_\mu(1+\gamma_5)\psi_e] + \text{H.c.}, \qquad (2)$$

where G is the usual weak coupling constant and $\hbar = c = 1$. The total rate for (1) then follows as[5]

$$R = \frac{2G^2\Delta^5}{15\pi^3}|\langle f|i\rangle|^2. \qquad (3)$$

The matrix element in (3) refers to the initial-final overlap integral between the relevant atomic states, and Δ is the difference in binding energies of the states.

We consider transitions wherein an electron with zero orbital angular momentum in the L atomic shell converts to a strange electron in the K shell, with the K shell initially occupied by two normal electrons and either zero or one strange electrons. The result of rough numerical estimates based on (3) is that the corresponding lifetime is of order 10^{10} y, the age of the universe,[6] for atomic number Z in the range ~20-25. The lifetime decreases rapidly with Z, roughly as Z^{-8}. Thus those atoms with $Z \gtrsim 30$ (allowing for error) would at present contain four particles in the K shell if the process (1) were allowed, in blatant contradiction with experiment.

We conclude that (1) does not occur at rates characteristic of weak interactions. Therefore, either strange electrons and strange neutrinos do not both exist, or the terms in the interaction Hamiltonian which would lead to (1) cancel or are greatly suppressed, or Coulomb's law for strange electrons is valid over laboratory distances but not below a distance of order 10^{-10} cm.[3]

In view of the difficulties with the electrodynamics of strange electrons,[3] the simplest assumption seems to us to be that they do not exist. The hypothesis that strange muons exist, but that strange electrons do not, would have to be reconciled with the impressive amount of experimental evidence for e-μ universality in weak interactions. We turn then to the question of strange neutrinos.

Weiner[1] suggests an experimental search for the decay

$$K^+ \rightarrow \pi^+ + \bar{\nu} + \bar{\nu}^S. \tag{4}$$

We would expect (4) to occur at a rate comparable with those of the other three-body semileptonic K decay modes, if indeed strange neutrinos exist and if neutral leptonic-current effects are suppressed only by normal conservation laws.

Many experiments involving decays of stopping K^+ have been performed in recent years. It would be surprising if (4) were to occur at a rate comparable with the $K_{\mu 3}$ mode—a three-body semileptonic mode—without having been reported, because the momentum spectrum of the pion from (4) extends to a higher value (227 MeV/c) than do the momenta of all other pions ($\leq$205 MeV/c) from K^+ decay (neglecting the rare radiative modes). We have studied in particular, the work by Auerbach *et al.*,[7] and we conclude that the momentum spectrum of K^+-decay pions above 215 MeV/c is suppressed by an order of magnitude relative to the muon spectrum in the $K_{\mu 3}$ mode.[8] This is evidence either against the existence of strange neutrinos, or that some mechanism other than that provided by conservation laws acts to suppress neutral currents.

We feel that neither strange charged leptons nor neutral leptonic currents are likely to exist, but that the question of strange neutrinos merits further study. Some thoughts in this direction follow.

A weak-interaction Lagrangian density whose semileptonic part manifestly conserves strangeness is

$$\mathfrak{L}_{\text{weak}} = \sum_{i=V,A} \frac{G}{\sqrt{2}} [J_{\lambda(1)}{}^i j_{\lambda(-1)} \sin\theta^i + J_{\lambda(0)}{}^i j_{\lambda(0)} \cos\theta^i] + \text{H.c.} + \mathfrak{L}_{\text{leptonic}} + \mathfrak{L}_{\text{nonleptonic}}, \tag{5}$$

where θ^V is the Cabibbo angle and $J_{\lambda(0,1)}{}^V$ are the $\Delta S = 0, 1$ parts, respectively, of the Cabibbo hadron current (defined without the θ factors) for the vector interaction, and similarly for the axial interaction[9]; where $j_{\lambda(0)}$ is the usual lepton current; and where $j_{\lambda(-1)}$ differs from $j_{\lambda(0)}$ by the replacement $\nu \rightarrow \bar{\nu}^S$ (with the strange-neutrino labeling convention of Table I. Apart from neutrino-induced reactions, the measurable predictions of (5) for semileptonic processes are precisely those of the Lagrangian of the Cabibbo theory. This Lagrangian is successful in explaining semileptonic decays,[9] and therefore so is (5).

Nonleptonic interactions still do not conserve strangeness in this picture; and the strangeness conservation (5) in semileptonic processes is achieved at the expense of the elegant idea that " 'the' hadronic weak current couples with 'the' leptonic current." However, it is difficult to defend this latter idea within the framework of the Cabibbo theory itself: The parameter θ would have to be considered as being part of the hadronic current, as opposed to being associated with the leptonic current or with the interaction itself. This in turn implies that the parameter should be a property of the purely hadronic interactions. In fact, it is not a property of the *known* purely hadronic interactions.[9] Our own position regarding the relative elegance of the two schemes is neutral.

We also suggest that there may be only *one* ν^S, equally coupled to μ and to e. In this way the strangeness conservation mentioned above requires the addition of only one new spinor field.

High-energy neutrino experiments are most relevant to the issue of strange neutrinos. As Weiner has pointed out,[1] a reaction induced by a neutrino (assumed strange) from kaon decay must have one unit of strangeness in the final state. Now, small fractions of events with electrons have been observed in the neutrino experiments,[10] although the μ-type neutrinos from π decay predominate. These are presumably elastic (nucleon plus electron) nonstrange events. They have been explained reasonably well as being induced by the smaller flux of e-type neutrinos from the K_{e3} decay.[10] This would seem to constitute evidence against the hypothesis of strange neutrinos, although the uncertainties are sizable.

Finally, we note that if only K-decay neutrinos can produce *single*-strange-particle final states,[11] then fewer such events are expected than if π

neutrinos are also operative, by a factor of the order of the charged beam K/π ratio. This appears superficially to be a simple order-of-magnitude test. The early published data[10] do not appear to us to be extensive enough to measure the expected rates in either case, but perhaps the situation has since improved.

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[1] R. M. Weiner, Phys. Rev. Letters 20, 396 (1968).

[2] It is stated in Table III of Ref. 1 that the ν has lepton number -1. This is inconsistent with the overall scheme and we assume it to be a typographical error. Also, it is stated in Ref. 1 that nuclear capture of strange muons is forbidden; the process $\mu^{-s}+p\rightarrow n+\nu^s$ has been overlooked if our understanding of the paper is correct.

[3] Weiner (Ref. 1) has noted that the electrodynamics of strange electrons must be unconventional because production of strange pairs by photons is apparently not observed, and one may well wonder if strange electrons can be bound in atoms at all. However, we note that if the strange electron exists, then its electric charge must be normal at very small momentum transfer, because the electrons from the decays of strange particles are deflected normally by static magnetic fields (to within a few percent). If the electrodynamics is to be altered by means of a "cutoff," then our estimates are still valid if the cutoff is $\gtrsim$100 keV/c.

[4] The helicities of the ν and the ν^s must be opposite if the assignments in Table I are to be reconciled with K, π, and μ decay experiments. This gives the Hamiltonian (2) its somewhat peculiar $V+A$ structure.

[5] We assume mass degeneracy of the electrons and we make two approximations: (a) non-relativistic electrons; and (b) neutrino wavelengths large in comparison with the relevant atomic dimensions. The latter is rather poor.

[6] If the currently favored cosmological picture is valid, the universe was at a temperature of $\sim 10^{10}\,^\circ$K at some time of order 10^{10} y ago and subsequently cooled rapidly. In particular, the temperature fell below the value above which stable atoms would not exist in the first $\sim 10^4$-10^5 y. [R. H. Dicke, P. J. E. Peebles, P. G. Roll, and D. T. Wilkinson, Astrophys. J. 142, 414 1965)].

[7] L. B. Auerbach, J. MacG. Dobbs, A. K. Mann, W. K. McFarlane, D. H. White, R. Cester, P. T. Eschstruth, G. K. O'Neill, and D. Yount, Phys. Rev. 155, 1505 (1967). This branching-ratio study contains references to several earlier experiments.

[8] Specifically, we have studied the range-momentum scatter plot, Fig. 7 in Ref. 7, in the region 215-230 MeV/c, including the part corresponding to degraded pions, and have compared with the numbers listed in their text for the muon spectrum, taking account of backgrounds. Their momentum resolution was quite good, and the bias against detection of high-momentum pions was small in virtue of measuring the momentum of each paricle prior to its traversing appreciable amounts of material.

[9] N. Cabibbo, Phys. Rev. Letters 10, 531 (1963). See also N. Cabibbo, in Proceedings of the Thirteenth International Conference on High-Energy Physics, Berkeley, 1966 (University of California Press, Berkeley, Calif., 1967), p. 29. The question of the origin of the Cabibbo angle is discussed in the second of these papers.

[10] G. Danby et al., Phys. Rev. Letters 9, 36 (1962); M. M. Block et al., Phys. Letters 12, 281 (1964); J. K. Bienlein et al., Phys. Letters 13, 80 (1964). The latter authors observe an e/μ ratio of $(1.7\pm 0.5)\,\%$, while the expected ratio is 0.6 %. The discrepancy is interpreted as arising from lack of precise knowledge of the fluxes.

[11] The relevant final states, excluding pion production, are $n+K^++l^-$, $p+K^0+l^-$, $p+K^++l^-$ for K^+ decay neutrinos, and $(\Lambda,\Sigma^0)+l^+$, Σ^-+l^+ for K^- decay neutrinos.