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Neutral Lepton Currents and Neutrino Detection*

R. W. KING†
Physics Department, Purdue University, Lafayette, Indiana
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The interactions of neutrinos with complex nuclei are explored assuming the existence of a neutral lepton current.

LEE and Yang[1] have investigated the theoretical implications of high-energy neutrino experiments. The purpose of this note is to point out that the existence of a neutral lepton current makes possible new detection techniques for neutrinos. If reactions such as

$$\nu+p \rightarrow \nu+p \quad \text{and} \quad \nu+n \rightarrow \nu+n \qquad (1)$$

exist, then numerous inelastic processes in complex nuclei should occur and these processes offer new methods for detecting neutrinos. It also appears that some of the new techniques need not await the development of high-energy neutrino sources.

If we consider the possibility of a neutral current, perhaps coupled to a neutral intermediate field, then a complex nucleus can de-excite by the emission of $(\nu,\bar{\nu})$ pairs.[2] While de-excitation by this mode would never be observed because of the overwhelming competition of electromagnetic radiation, the inverse process of exciting a complex nucleus by neutrino or antineutrino bombardment lends itself to experimental observation. For complex nuclei the inverse process

$$\nu+{}_ZX_N \rightarrow {}_ZX^*{}_N+\nu \qquad (2)$$

bears the same relation to $(\nu,\bar{\nu})$ emission as does inverse beta decay to $(e^-,\bar{\nu})$ emission.

Since reactors provide high-flux low-energy sources of antineutrinos our first concern is with low-threshold reactions. It seems appropriate then to consider detecting low-energy antineutrino excitation of a nucleus by observing the subsequent γ emission. In order to reduce background, $\gamma-\gamma$ coincidence measurements could be employed where coincidences are recorded between γ rays of various energy that feed the first excited state and a γ ray of characteristic energy emitted by the first excited state. It has been suggested[3] that delayed coincidences would be advantageous, and while it is not the purpose of this note to examine all possible target materials, it is perhaps worth while to point out that once all the desirable target features are determined, one has the entire chart of the nuclides from which to choose (including the nuclei of scintillating materials).

Since the interaction in question requires a different type of intermediate field, the possibility exists that the strength of the interaction is somewhat different from the usual weak interaction (preferably stronger). However, for purposes of estimating the cross section we shall assume a coupling constant and form of the interaction characteristic of beta decay,[4]

$$(8)^{\frac{1}{2}}G(\bar{\psi}_n\gamma_\mu a\psi_n)(\bar{\psi}_\nu\gamma_\mu a\psi_\nu) \quad \text{with} \quad a=\tfrac{1}{2}(1+\gamma_5),$$

where the electron has been replaced by a neutrino. The expression for the cross section for reaction (2) is then

$$\sigma=\frac{8G^2}{\pi^2\hbar^4c^4}\Big[\sum_f |(f|M|i)|^2\Big]\big[E_\nu-\Delta E\big]^2, \qquad (3)$$

where G is the coupling constant, and the matrix element is the nuclear matrix element associated with the decay of the excited state to the ground state by $(\nu,\bar{\nu})$ emission. Allowed type transitions will dominate, so usually this matrix element will be similar to the Gamow-Teller $|\int\boldsymbol{\sigma}|^2$ except for the charge displacement operator.[5] E_ν is the energy of the bombarding neutrino and ΔE is the energy of the nuclear excitation.

The exact cross section obviously depends on the selection of the target but it is not difflcult to select cases where the cross section per antineutrino (averaged over a reactor spectrum of antineutrinos) is of order 10^{-43} cm^2. This value for the cross section is quite comparable to that of the Cowan-Reines experiment.[6]

We remark finally that neutral currents also imply that reactor antineutrinos are capable of producing the reaction

$$\nu+\text{Be}^9 \rightarrow \alpha+\alpha+n+\nu, \qquad (4)$$

because of the low threshold. Such a reaction might provide an even better means of detection. A detailed calculation of the matrix elements in Eq. (3) for this reaction is in progress. Future sources of high-energy neutrinos present many possibilities similar to reaction (4), including radioactive labeling of the reaction products.

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† Alfred P. Sloan Research Foundation Fellow.
[1] T. D. Lee and C. N. Yang, Phys. Rev. Letters **4**, 307 (1960).
[2] *Note added in proof.* A neutral intermediate field with a coupling strength comparable to that of the charged intermediate field is not usually thought to be operative because of the absence of certain modes in the decay of strange-particles and the muon. However, there is at present no experimental evidence concerning this conjecture when normal baryons and normal leptons are the interacting particles.
[3] E. Bleuler (private communication).
[4] R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 193 (1957).
[5] Fermi-type matrix elements will vanish since they cannot connect different states of the same nucleus.
[6] F. Reines and C. L. Cowan, Jr., Phys. Rev. **113**, 273 (1959); R. W. King and J. F. Perkins, Phys. Rev. **112**, 963 (1958).