Treiman, Phys. Rev. Letters 22, 500 (1969); G. Altarelli and H. R. Rubinstein, Phys. Rev. 178, 2111 (1969); K. Bardakci and N. Pak, Lett. Nuovo Cimento 4, 719 (1972).

[8] We have some reason to expect that the Pomeranchukon will act as a better SU(3) singlet in the current amplitudes than in the pseudoscalar meson amplitudes since SU(3) mass breaking will be insignificant at $Q^2 \to \infty$.

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"Exotic" Hadron Weak Currents*

R. J. Oakes
Department of Physics, Northwestern University, Evanston, Illinois 60201
and Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany

and

H. Primakoff
Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania 19104

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The possibility that the hadron weak current contains an "exotic" strangeness-conserving isotensor component and/or an "exotic" strangeness-changing isospin-$\frac{3}{2}$ component is considered. Several neutrino experiments which can provide tests for the presence of such components are briefly described.

Phenomenologically, the semileptonic weak interactions are at least approximately described by a Hamiltonian of the form (hadron weak current) × (lepton weak current) and the hadron weak current is known to contain strangeness-conserving isovector ($\Delta S=0$, $\Delta Q=\pm1$, $|\Delta\vec{I}|=1$) and strangeness-changing isospinor ($\Delta S=\pm1$, $\Delta Q=\pm1$, $|\Delta\vec{I}|=\frac{1}{2}$) components. The presence of other, so-called "exotic" components in the hadron weak current is still not excluded, particularly in view of the possibility that the hadron electromagnetic current has an "exotic" isotensor component in addition to the established isoscalar and isovector components.[1] In this note we briefly describe how appropriate neutrino experiments can provide tests for the presence in the hadron weak current of a strangeness-conserving isotensor component ($\Delta S=0$, $\Delta Q=\pm1$, $|\Delta\vec{I}|=2$) as well as a strangeness-changing isospin-$\frac{3}{2}$ component ($\Delta S=\pm1$, $\Delta Q=\pm1$, $|\Delta\vec{I}|=\frac{3}{2}$).

To begin, we recall that the cross section for production of the nucleon isobar $\Delta(1236)$ ($I=\frac{3}{2}$, $J^P=\frac{3}{2}^+$) by neutrinos incident on a nucleon target $[\nu_\mu(k)+N(p)\to\Delta(p')+\mu^-(k')]$ is of the form

$$\frac{d\sigma}{dt}=\frac{G^2}{16\pi(pk)^2}H_{\alpha\beta}L^{\alpha\beta}, \tag{1}$$

where $t=(p'-p)^2=(k-k')^2$, G is the semileptonic strangeness-conserving weak coupling constant, the lepton factor is

$$\begin{aligned}L_{\alpha\beta}&=L^*_{\beta\alpha}\\&=k_\alpha k'_\beta+k'_\alpha k_\beta-(kk')g_{\alpha\beta}+i\epsilon_{\alpha\beta\rho\sigma}k^\rho k'^\sigma,\end{aligned} \tag{2}$$

and the hadron factor is

$$\begin{aligned}H_{\alpha\beta}&=H^*_{\beta\alpha}\\&=\sum_{\text{spins}}\langle\Delta|J_\alpha|N\rangle\langle N|J^\dagger_\beta|\Delta\rangle\,.\end{aligned} \tag{3}$$

If time-reversal invariance is valid, which we shall assume, then the symmetric (real) part of $H_{\alpha\beta}$ is even under parity, containing just the VV and AA cross terms, while the antisymmetric (imaginary) part of $H_{\alpha\beta}$ contains the VA and AV cross terms and is odd under parity. If the strangeness-conserving hadron weak current J_α has an isotensor component in addition to the usual isovector component $[\cos\theta(V-A)_\alpha^{(1+i2)}]$, then its matrix elements are of the form

$$\langle\Delta^{++}|J_\alpha|p\rangle=\langle\Delta\|J_\alpha\|N\rangle_1-(\tfrac{1}{5})^{1/2}\langle\Delta\|J_\alpha\|N\rangle_2 \tag{4}$$

and

$$\langle\Delta^{+}|J_\alpha|n\rangle=(\tfrac{1}{3})^{1/2}\langle\Delta\|J_\alpha\|N\rangle_1+(\tfrac{3}{5})^{1/2}\langle\Delta\|J_\alpha\|N\rangle_2\,. \tag{5}$$

Here $\langle\Delta\|J_\alpha\|N\rangle_1$ and $\langle\Delta\|J_\alpha\|N\rangle_2$ are the reduced matrix elements between the indicated states of the isovector and isotensor components of J_α, respectively, and each contains both V and A parts.

To obtain the cross section for the corresponding antineutrino processes $[\bar{\nu}_\mu(k)+N(p)\rightarrow\Delta(p')+\mu^+(k')]$ one simply replaces $L_{\alpha\beta}$ by $L^*_{\alpha\beta}$ and J_α by $J^\dagger_\alpha$. The matrix elements of $J^\dagger_\alpha$ in terms of the reduced matrix elements $\langle\Delta\|J_\alpha\|N\rangle_1$ and $\langle\Delta\|J_\alpha\|N\rangle_2$ are

$$\langle\Delta^0|J^\dagger_\alpha|p\rangle=(\tfrac{1}{3})^{1/2}\langle\Delta\|J_\alpha\|N\rangle_1-(\tfrac{3}{5})^{1/2}\langle\Delta\|J_\alpha\|N\rangle_2 \tag{6}$$

and

$$\langle\Delta^-|J^\dagger_\alpha|n\rangle=\langle\Delta\|J_\alpha\|N\rangle_1+(\tfrac{1}{5})^{1/2}\langle\Delta\|J_\alpha\|N\rangle_2\,. \tag{7}$$

We also note that $\langle N'\|J_\alpha\|N\rangle_2=0$ even if an isotensor component of J_α is present so that the processes $\nu_\mu+n\rightarrow p+\mu^-$ and $\bar{\nu}_\mu+p\rightarrow n+\mu^+$ would be unaffected by the actual existence of such an isotensor component.

Rather than explicitly combine Eqs. (1)–(7) to obtain detailed formulas for the cross sections we simply note the following main points: If only the isovector current is present in the weak interactions, that is if $\langle\Delta\|J_\alpha\|N\rangle_2=0$, then[2]

$$\frac{d\sigma}{dt}(\nu_\mu+p\rightarrow\Delta^{++}+\mu^-)-3\frac{d\sigma}{dt}(\nu_\mu+n\rightarrow\Delta^++\mu^-)=0 \tag{8}$$

and

$$\frac{d\sigma}{dt}(\bar{\nu}_\mu+n\rightarrow\Delta^-+\mu^+)-3\frac{d\sigma}{dt}(\bar{\nu}_\mu+p\rightarrow\Delta^0+\mu^+)=0\,. \tag{9}$$

Also, the sum and difference

$$\frac{d\sigma}{dt}(\nu_\mu+p\rightarrow\Delta^{++}+\mu^-)\pm\frac{d\sigma}{dt}(\bar{\nu}_\mu+n\rightarrow\Delta^-+\mu^+) \tag{10}$$

are, respectively, proportional to the $\{VV,AA\}$ and $\{VA,AV\}$ cross terms in the hadron factor $H_{\alpha\beta}$ of the cross sections. If in addition to the isovector current there is also an isotensor current, then the right-hand side of Eqs. (8)–(9) no longer vanish but are proportional to the isovector-isotensor interference terms.[3] Furthermore, the sum and difference

$$\frac{d\sigma}{dt}(\nu_\mu+p\rightarrow\Delta^{++}+\mu^-)\pm\frac{d\sigma}{dt}(\bar{\nu}_\mu+n\rightarrow\Delta^-+\mu^+)-3\left[\frac{d\sigma}{dt}(\nu_\mu+n\rightarrow\Delta^++\mu^-)\pm\frac{d\sigma}{dt}(\bar{\nu}_\mu+p\rightarrow\Delta^0+\mu^+)\right] \tag{11}$$

are, respectively, proportional to the $\{VV,AA\}$ and $\{VA,AV\}$ cross terms in $H_{\alpha\beta}$ arising only from the interfering isovector-isotensor terms. Independent of the isovector-isotensor interference terms, the $\{VV,AA\}$ and $\{VA,AV\}$ cross terms arising only from the isovector current are, respectively, now measured by the sum and difference[3]

$$\frac{d\sigma}{dt}(\nu_\mu+p\rightarrow\Delta^{++}+\mu^-)\pm\frac{d\sigma}{dt}(\bar{\nu}_\mu+n\rightarrow\Delta^-+\mu^+)+\frac{d\sigma}{dt}(\nu_\mu+n\rightarrow\Delta^++\mu^-)\pm\frac{d\sigma}{dt}(\bar{\nu}_\mu+p\rightarrow\Delta^0+\mu^+) \tag{12}$$

rather than by the sum and difference in Eq. (10).

Clearly, the above arguments can be extended to the strangeness-changing hadron weak current. By comparing the processes[4] $\bar{\nu}_\mu+p\rightarrow\Sigma^0+\mu^+$ and $\bar{\nu}_\mu+n\rightarrow\Sigma^-+\mu^+$ one can search for a $|\Delta\vec{I}|=\frac{3}{2}$ strangeness-changing current[5] in addition to the usual $|\Delta\vec{I}|=\frac{1}{2}$ strangeness-changing current. The relevant matrix elements are (here J'_α is the strangeness-changing hadron weak current)

$$\langle\Sigma^0|J'^\dagger_\alpha|p\rangle=(\tfrac{1}{2})^{1/2}\langle\Sigma\|J'_\alpha\|N\rangle_{1/2}-(\tfrac{1}{2})^{1/2}\langle\Sigma\|J'_\alpha\|N\rangle_{3/2} \tag{13}$$

and

$$\langle\Sigma^-|J'^\dagger_\alpha|n\rangle=\langle\Sigma\|J'_\alpha\|N\rangle_{1/2}+\tfrac{1}{2}\langle\Sigma\|J'_\alpha\|N\rangle_{3/2}\,, \tag{14}$$

and the difference

$$2\frac{d\sigma}{dt}(\bar{\nu}_\mu+p\rightarrow\Sigma^0+\mu^+)-\frac{d\sigma}{dt}(\bar{\nu}_\mu+n\rightarrow\Sigma^-+\mu^+) \tag{15}$$

no longer vanishes[2] but is proportional to the VV, AA, VA, and AV interference terms between the $|\Delta\vec{I}|=\frac{1}{2}$ and $|\Delta\vec{I}|=\frac{3}{2}$ matrix elements.[3] Independent of the existence of a $|\Delta\vec{I}|=\frac{3}{2}$ current, the sum[3]

$$\frac{d\sigma}{dt}(\bar{\nu}_\mu+p\rightarrow\Sigma^0+\mu^+)+\frac{d\sigma}{dt}(\bar{\nu}_\mu+n\rightarrow\Sigma^-+\mu^+) \tag{16}$$

involves only the $|\Delta\vec{I}|=\frac{1}{2}$ (VV, AA, VA, and AV) matrix elements.

Finally, we note that a neutrino-nucleus quasi-elastic scattering process such as ($l=e$ or μ)

$$\nu_l+{}^{16}\mathrm{O}\rightarrow{}^{16}\mathrm{F}(I=2,J^P=0^+;E_{\mathrm{exc}}\cong9.9\text{ MeV})+l^- \tag{17}$$

or a nuclear muon-capture process such as

$$\mu^-+{}^{16}\mathrm{O}\rightarrow{}^{16}\mathrm{N}(I=2,J^P=0^+;E_{\mathrm{exc}}=9.928\text{ MeV})+\nu_\mu \tag{18}$$

can occur if the strangeness-conserving hadron weak current J_α contains an isotensor component.[6] In fact, if such $|\Delta\vec{I}|=2$ processes are actually observed, one would conclude that not only does J_α possess an isotensor component but that, in addition, the lepton weak current interacts with an effective intranuclear hadron weak current which is not exclusively associated with individual nucleons. This last conclusion is a consequence of the above-mentioned fact that $\langle N'\|J_\alpha\|N\rangle_2=0$; thus the presumed nonvanishing matrix elements $\langle {}^{16}\mathrm{F}(I=2)|J_\alpha|{}^{16}\mathrm{O}\rangle$ and $\langle {}^{16}\mathrm{N}(I=2)|J_\alpha^4|{}^{16}\mathrm{O}\rangle$ must contain a paired nucleon or "meson-exchange" contribution proportional to a sum of matrix elements of the type $\langle M\{N\}'^{(a)}\|J_\alpha\|N^{(a)}\rangle_2$ each multiplied by the corresponding M-meson propagator and the $M\{N\}'^{(b)}N^{(b)}$ (strong-interaction) vertex function,[7] and/or an individual nucleon-isobar contribution proportional to a matrix element of the type $\langle \Delta\|J_\alpha\|N\rangle_2$ where the Δ is assumed to be "permanently" present in the ^{16}O nucleus or the ^{16}F, ^{16}N nuclei.[8]

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[1] A. I. Sanda and G. Shaw, Phys. Rev. Letters 24, 1310 (1970); Phys. Rev. D 3, 243 (1971); A. Donnachie and G. Shaw, *ibid.* 5, 1117 (1972). For a general review of this unsettled question see A. Donnachie, in *Proceedings of the International Symposium on Electron and Photon Interactions at High Energies, 1971,* edited by N. B. Mistry (Cornell Univ. Press, Ithaca, N. Y., 1972). It is, of course, also possible that, for example, neither the hadron electromagnetic current nor the hadron polar weak current has "exotic" components and that it is only the hadron axial current which has such "exotic" components.

[2] M. Block, Phys. Rev. Letters 12, 262 (1964). We thank Professor R. Winston for calling this reference to our attention.

[3] We neglect terms quadratic in the "exotic" currents since, if present at all, these must be small.

[4] Here Σ denotes any one of the $S=-1$, $I=1$ baryons.

[5] A polar $\Delta S=\pm1$, $\Delta Q=\pm1$, $|\Delta\vec{I}|=\frac{3}{2}$ current is limited to less than about 5% of the polar $\Delta S=\pm1$, $\Delta Q=\pm1$, $|\Delta\vec{I}|=\frac{1}{2}$ current by available K_{l3} data. Regarding the effect of an axial $\Delta S=\pm1$, $\Delta Q=\pm1$, $|\Delta\vec{I}|=\frac{3}{2}$ current on the rates of the various hyperon decays see S. Pakvasa, A. McDonald, and S. P. Rosen, Phys. Rev. 181, 1948 (1969).

[6] $^{16}\mathrm{N}(I=2,\ J^P=0^+,\ E_{\mathrm{exc}}=9.928\ \mathrm{MeV})$ should deexcite itself relatively frequently by the emission of a high-energy photon: $^{16}\mathrm{N}(I=2,\ J^P=0^+,\ E_{\mathrm{exc}}=9.928\ \mathrm{MeV}) \to {}^{16}\mathrm{N}(I=1,\ J^P=1^-,\ E_{\mathrm{exc}}=0.3973\ \mathrm{MeV})+\gamma(9.531\ \mathrm{MeV})$ [followed by the emission of one or two low-energy photons as $^{16}\mathrm{N}(I=1,\ J^P=1^-,\ E_{\mathrm{exc}}=0.3973\ \mathrm{MeV})$ decays toward the ^{16}N ground state]. The main competition to this deexcitation by photon emission should arise from deexcitation by neutron emission: $^{16}\mathrm{N}(I=2,\ J^P=0^+,\ E_{\mathrm{exc}}=9.928\ \mathrm{MeV}) \to {}^{15}\mathrm{N}(I=\frac{1}{2},\ J^P,\ E_{\mathrm{exc}}<7.4\ \mathrm{MeV})+n$, which can occur since $^{16}\mathrm{N}(I=2,\ J^P=0^+,\ E_{\mathrm{exc}}=9.928\ \mathrm{MeV})$ is expected to have a small admixture of $I=1$ [of course, this $\gamma(9.531\ \mathrm{MeV})$ vs n branching ratio must be determined in an independent experiment where the $^{16}\mathrm{N}(I=2,\ J^P=0^+,\ E_{\mathrm{exc}}=9.928\ \mathrm{MeV})$ is produced, e.g., by $^3\mathrm{He}+{}^{14}\mathrm{C}\to p+{}^{16}\mathrm{N}$]. On the other hand, the various $^{16}\mathrm{N}(I=1,\ J^P,\ E_{\mathrm{exc}}\approx 10\ \mathrm{MeV})$ which will be produced in muon capture by ^{16}O via the isovector component of J_α, e.g., $^{16}\mathrm{N}(I=1,\ J^P,\ E_{\mathrm{exc}}=9.760)$ or $^{16}\mathrm{N}(I=1,\ J^P,\ E_{\mathrm{exc}}=9.813)$, should deexcite themselves almost exclusively by neutron emission. Entirely analogous remarks can be made about the deexcitation of $^{16}\mathrm{F}(I=2,\ J^P=0^+,\ E_{\mathrm{exc}}\cong 9.9\ \mathrm{MeV})$. One could, in addition, search for a nuclear muon-capture process such as $\mu^-+{}^{20}\mathrm{Ne}\to{}^{20}\mathrm{F}(I=2,\ J^P=0^+,\ E_{\mathrm{exc}}=6.513\ \mathrm{MeV})+\nu_\mu$ since $^{20}\mathrm{F}(I=2,\ J^P=0^+,\ E_{\mathrm{exc}}=6.513\ \mathrm{MeV})$ is stable against deexcitation by neutron (or proton or α-particle) emission and so must deexcite itself by photon emission.

[7] For recent discussions of such "meson-exchange" contributions to the intranuclear hadron weak current, see D. O. Riska and G. E. Brown, Phys. Letters 32B, 662 (1970); M. Chemtob and M. Rho, Nucl. Phys. A163, 1 (1971); E. Fischbach, E. P. Harper, Y. E. Kim, A. Tubis, and W. K. Cheng, Phys. Letters 38B, 8 (1972).

[8] For a general discussion of the possibility that various nucleon isobars are "permanently" present in nuclei, see A. K. Kerman and L. S. Kisslinger, Phys. Rev. 180, 1483 (1969); H. Arenhövel, M. Danos, and H. T. Williams, Phys. Letters 31B, 109 (1970); H. Primakoff and S. P. Rosen, Phys. Rev. 184, 1925 (1969).