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NUCLEAR PARITY VIOLATION TESTS OF NON-LEPTONIC WEAK CURRENTS

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A B S T R A C T

Nuclear gamma-ray transitions are proposed to detect a $\Delta I = 1$, $\Delta Y = 0$ weak interaction. The circular polarizations in ^{18}F and ^{10}B transitions may be particularly suitable.

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One of the unsolved questions of weak interactions is the nature of the non-leptonic interaction. Is it of the current-current form? Within the framework of such a theory, the vanishing of the 27-plet contribution to the s wave decay of the baryons ¹⁾ and the agreement of the p wave decay with the Lee-Sugawara relation ²⁾ has been conjectured to be due to (i) dynamical enhancement of the octet contributions ³⁾, or (ii) additional currents ⁴⁾. The recent experimental findings of parity-violating effects in nuclear physics ⁵⁾ suggest the possibility of distinguishing between hypotheses (i) and (ii) and of learning whether an isospin changing $\Delta I = 1$, strangeness non-changing $\Delta Y = 0$, weak, non-leptonic interaction exists at all. It is the aim of this note to suggest some experiments for this purpose.

If a current-current interaction is assumed, then the nucleon parity violating potential has contributions from both $\Delta Y = 0$ and $\Delta Y = 1$ currents. The former potential, u , carries isospin change $\Delta I = 0, 2$, whereas the latter one, v , corresponds to $\Delta I = 1$ ³⁾. In the normal current-current theory, u is proportional to $\cos^2 \theta$, where θ is the Cabibbo angle, and has contributions from 2π , ρ , ω , ϕ exchanges ^{3), 6)}; its magnitude has been estimated by Blin-Stoyle, Barton and Michel ⁶⁾. The potential v , on the other hand, is proportional to $\sin^2 \theta$ and has a long-range contribution from one $\pi^\pm$ exchange. It can be calculated more reliably than u by means of current algebra and $SU(3)$ symmetry. This has been done by McKellar, with the assumption of no extra currents ⁷⁾.

The most straightforward test of the nuclear parity-violating force is very low energy $n-p$ capture. As shown by Danilov ⁸⁾, the $\Delta I = 0$ and $\Delta I = 1$ force components can be separated unambiguously in this experiment. However, the parity-violating effects are extremely small and probably not measurable with present techniques ⁹⁾.

Suitable tests to distinguish u from v and (i) from (ii) require light nuclei with levels of known isospin I . Electromagnetic transitions between levels $|J_I^P\rangle$ and $|K_I^{P'}\rangle$, together with measurements

of the circular polarization of the emitted photons are perhaps best suited for such experiments ¹⁰⁾. We seek tests that are sensitive to v but not u . For this purpose, we choose : (a) self-conjugate light nuclei, (b) parity-conserving transitions between levels of $I = I' = 0$, (c) parity-conserving M1 or E1 transitions. With the conditions (a)-(c), M1 and E1 transition matrix elements are reduced by one and two orders of magnitude, respectively ¹¹⁾. The effects of the weak parity-violating force u are to admix states $|J_{0,2}^{-P}\rangle$ to $|J_0^P\rangle$, whereas v admixes states $|J_1^{-P}\rangle$. Since isospin 2 levels are generally far removed in energy, they are neglected below. Examples of transitions that satisfy criteria (a)-(c) were found in ^{10}B , ^{14}N and ^{16}F , and are summarized in the Table. (The E1 transition in ^{10}B has been suggested earlier ³⁾).

Estimates of the parity violation admixtures, $\mathcal{F}_0$ and $\mathcal{F}_1$ (for $I = 0$ and $I = 1$ states, respectively) are made as follows. We assume two valence nucleons, and write the weak parity-violating interactions for these nucleons as

$$W = w_n + w_p + u + v = U + V, \quad (1)$$

where w_n and w_p are effective single-particle parity-violating potentials, which are split into $\Delta I = 0$ and $\Delta I = 1$ components. Estimates of the matrix elements of w have been made most recently by McKellar ¹²⁾. These potentials admix states to $|J_0^P\rangle$ and $|K_C^{P'}\rangle$; we have in an obvious notation

$$\begin{aligned} |J\rangle &= |J_0^P\rangle + \sum_n |J_1^{-P}(n)\rangle \frac{\langle J_1^{-P}(n) | V | J_0^P \rangle}{E_0 - E_1(n)} \\ &\quad + \sum_m |J_0^{-P}(m)\rangle \frac{\langle J_0^{-P}(m) | U | J_0^P \rangle}{E_0 - E_0(m)} \end{aligned}$$

$$\approx |J_0^P\rangle + \mathcal{F}_1 |J_1^{-P}(n)\rangle + \mathcal{F}_0 |J_0^{-P}(m)\rangle.$$

(2)

The last equation assumes that the sum over n or m is dominated by a single term. Indeed, to decrease the effects of u , it is desirable to (d) choose states $|J_0^P\rangle$ and $|K_0^{P'}\rangle$ which have close-lying neighbours $|J_1^{-P}\rangle$ or $|K_1^{-P'}\rangle$, but for which states $|J_0^{-P}\rangle$ and $|K_0^{-P'}\rangle$ are far removed in energy. There are two further factors which enhance the effects of V over those from U . Because of the short range strong repulsive interaction between nucleons the long range one pion exchange potential v is more effective than the shorter range u ¹²⁾. In addition the electromagnetic transitions from $|J_0^{-P}(n)\rangle \rightarrow |K_0^P\rangle$ or $|J_0^P\rangle \rightarrow |K_0^{-P'}(n)\rangle$ are hindered by the same factors as the parity-conserving transitions.

For numerical estimates of $\langle J_1^{-P'}(n_1)|V|J_0^P\rangle$, harmonic oscillator wave-functions for p and s - d shell nucleons were used with L - S coupling and with $M\omega \approx 0.3 \text{ fm}^{-2}$ ¹³⁾. For $J^P = 2^-(I=0)$ in ^{14}N , the matrix element $\langle 2_1^+|v|2_0^-\rangle$ was calculated to be $\approx 2 \times 10^{-8} \text{ MeV}$ and this value was used for all but ^{18}F . In the latter case the matrix element is more difficult to ascertain. The 0^- state almost certainly requires core excitation, which is not connected to the s - d shell 0^+ state by W . Although positive parity states have been studied in detail, much less is known about the negative parity states of ^{18}F . To obtain a crude estimate we assumed a residual interaction $=v$ between valence and core nucleons. For the 0^+ state we used the wave function of Kuo and Brown ¹⁴⁾ (transformed to L - S coupling) and $2s - 1p$ shell nucleons for the 0^- state. We estimate $\langle 0_1^+|v|0_0^-\rangle \approx 0.5 \times 10^{-8} \text{ MeV}$.

The known low-lying levels that can be admixed to those listed in the first three columns of the Table are employed to estimate $\mathcal{F}_1$. The dominant contributions come from levels, given in column five of the Table, which have large decay widths to $|K_0^{P'}\rangle$. For ^{18}F and for the $E1$ transition in ^{10}B the admixed states lie within 60 keV of $|J_0^P\rangle$.

The circular polarization is determined not only by $\mathcal{F}$, but also by R , the ratio of the parity forbidden electromagnetic transition matrix element to the allowed one; this was taken into account in arriving at the states listed in column five of the Table. The ratios R_1 , given in

column six, were obtained from measured decay widths ¹⁵⁾, scaled by $[E_0/E(n_1)]^3$, or from single particle estimates (for the M1 transition in ¹⁴N). The circular polarizations to be expected from the admixed $I = 1$ states are approximately equal to $F_1 R_1$ and are given in columns seven and eight of the Table for cases (i) and (ii) respectively.

In order to serve as tests of the weak currents, it is necessary that $F_0 R_0 \ll F_1 R_1$. The values of F_0 are more difficult to ascertain than those of F_1 because u is less well known than v . Michel ⁶⁾ suggests that, for ¹⁶O, $\langle w \rangle / \Delta E \approx 3 \times 10^{-7}$; this is larger than estimates made by McKellar ¹²⁾, who took the nucleon-nucleon repulsive core into account. However, F_0 would be increased by dynamical octet enhancement. Since we need only a crude estimate (upper limit) of the matrix elements of U , we used $F_0 \lesssim 6 \times 10^{-7} / \Delta E (\text{MeV})$. With values of R_0 estimated like those of R_1 , the admixture of $I = 0$ states gives rise to a circular polarization, $F_0 R_0$, given in the last column of the Table.

The requirement $F_0 R_0 \ll F_1 R_1$ eliminates the M1 transition in ¹⁰B and the E1 transition in ¹⁴N. Despite the lack of knowledge concerning the 0^- state in ¹⁸F (a defect that can be remedied by nuclear studies), this case and the M1 transition in ¹⁰B appear to be the most hopeful ones to explore the nature of the weak non-leptonic currents. However, the polarizations summarized in the Table are only order of magnitude estimates. A quantitative analysis requires that the wave-functions used give the measured decay rates. Such calculations are being undertaken.

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Nucleus	$J_0^P [E(\text{MeV})]$	$K_0^P [E(\text{MeV})]$	Primary multi-polarity	Important $J_1^{\pm P}(n)$ or $K_1^{\pm P}(n)$ $[E(\text{MeV})]$	R_1	$g_{1R1}^{\pm}$ $\times 10^{-6}$	$(g_{1R1}^{\pm})'$ $\times 10^{-6}$	$f_{0R0}^{\pm}$ $\times 10^{-6}$
^{10}B	$2^+(3.585)$	$3^+(0)$	M1	$2^-(7.480, 7.750)$	60	1	20	5
	$2^-(5.105)$	$1^+(0.717)$	E1	$2^+(5.159)$	10	4	80	0.6
^{14}N	$2^-(5.104)$	$1^+(0)$	E1	$2^+(9.170)$	150	1	20	8
	$2^+(7.030)$	$1^+(0)$	M1	$2^-(9.504)$	30	0.3	6	0.03
^{18}F	$0^-(1.080)$	$1^+(0)$	E1	$0^+(1.043)$	90	10	200	0.1

Possible electromagnetic transitions in light nuclei
to test weak interactions

REFERENCES

- 1) For a summary, see e.g. Proceedings of XIIIth International Conference on High Energy Physics, Berkeley (1966), University of California Press, p. 29 (1967) ;
H. Sugawara - Phys.Rev.Letters 15, 870, 997 (1965) ;
M. Suzuki - Phys.Rev.Letters 15, 986 (1965).
- 2) H. Sugawara - Progr.Theoret.Phys. 31, 213 (1964) ;
B.W. Lee - Phys.Rev.Letters 12, 83 (1964).
- 3) For references and discussion, see R.F. Dashen, S.C. Frautschi, M. Gell-Mann and Y. Hara, in M. Gell-Mann and Y. Ne'eman "The Eightfold Way", W.A. Benjamin, Inc., New York, p. 254 (1964).
- 4) See e.g., B. d'Espagnat - Phys.Letters 7, 209 (1963).
- 5) V.M. Lobashov, V.A. Nazarenko, L.F. Saenko, L.M. Smotritskii and G.I. Kharkevich - Zh.Eksper.Teor.Fiz. 5, 73 (1967) ; English Translation JETP Letters 5, 59 (1967) ;
Yu.G. Abov, P.A. Krupchitsky, M.Y. Bulgakov, O.N. Yermakov and I.L. Karpikhin - Phys.Letters 27B, 16 (1968).
Earlier references are given in these articles.
- 6) R.J. Blin-Stoyle - Phys.Rev. 118, 1605 and 120, 181 (1960) ;
G. Barton - Nuovo Cimento 19, 512 (1961) ;
F.C. Michel - Phys.Rev. 133, B329 (1964).
- 7) B.H.J. McKellar - Phys.Letters 26B, 107 (1967).
- 8) G.S. Danilov - Phys.Letters 18, 40 (1965).
- 9) See, however, V.M. Lobashov - Yadernaya Fizika 2, 957 (1965) ; Transl. Soviet J.Nuclear Phys. (USA) 2, 683 (1965).

8.

- 10) See e.g., D.H. Wilkinson - Phys.Rev. 109, 1603 (1958), for a discussion of classes of tests.
- 11) L.A. Radicati - Phys.Rev. 87, 521 (1952) ;
M. Gell-Mann and V.L. Telegdi - Phys.Rev. 91, 169 (1953) ;
G. Morpurgo - Phys.Rev. 110, 721 (1958).
- 12) B.H.J. Mc Kellar - Phys.Rev.Letters 20, 1542 (1968).
- 13) W.W. True - Phys.Rev. 130, 1530 (1963).
- 14) T.T.S. Kuo and G.E. Brown - Nuclear Phys. 85, 40 (1966) ;
- 15) S.J. Skorka, J. Hertel and T.W. Retz-Schmidt - "Compilation of Electromagnetic Transition Rates in Light Nuclei ($A \leq 40$)", Nuclear Data A2, 347 (1966). The width of the 1.04 MeV 0^+ level of ^{18}F has recently been determined by A.E. Blaugrund, D.H. Youngblood, G.C. Morrison and R.E. Segel - Phys.Rev. 158, 893 (1967).