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PARITY NON-CONSERVATION IN NUCLEI

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Abstract

A general weak-interaction Hamiltonian can be divided into leptonic, semileptonic, strangeness-violating nonleptonic, and strangeness-conserving nonleptonic sectors

$$H_W = H_L + H_{SL} + H_{NL}^{S=1} + H_{NL}^{S=0} . \qquad (1)$$

The last sector can be studied by investigating parity-violating (PV) nuclear forces.

The study of these forces is complicated and requires four main steps |1|

Weak Hamiltonian

Weak PV nuclear potential

Theoretical prediction of nuclear processes

Experiment

The actual calculation of the potential is based on the diagram in fig. 1 and is described in detail in ref. |1|.

The parity-violating NNπ amplitude is estimated on the basis of the sum rules connecting it to the s-wave nonleptonic hyperon decay amplitude

$$A(B^a \to B' + \pi^b) = A(B^a_b) \qquad (2)$$

If both $H_{NL}^{|\Delta S|=1}$ and $H_{NL}^{\Delta S=0}$ transform as components of the **same** SU(3) octet tensor, the sum rule is

$$F|A(\Xi^-_-) - 2A(\Lambda^0_-)| - \frac{3}{2}A(n^0_-) = 0 \quad . \tag{3}$$

Here F depends on the particular H_W and can be calculated. For unified gauge field theories, simple-minded approaches tried to obtain modifications of the sum rule (3) by postulating octet dominance |3,4|. In gauge field theories, $H_{NL}^{|\Delta S|=1}$ and $H_{NL}^{\Delta S=0}$ are no more components of the same SU(3) octet tensors. Compared with the standard Cabibbo model |3,4|, the three-triplet model of the Lee-Prentki-Zumino type |5| gives

$$\frac{F_{LPZ}}{F_C} \simeq -\frac{1}{\sin^2\theta_C} \frac{35 - 24\cos 2\theta_W + \sigma}{11 + \sigma} \tag{4}$$

$$\sigma = st^{-1} \quad .$$

Here s and t refer to the reduced matrix elements of inequivalent SU(3) octet tensors. An enhancement as large as 70 (t=0) is possible. A model which employs an additional V ↔ A antisymmetric tensor (a) is the Georgi-Glashow model |6|, for which |4|

$$\frac{F_{GG}}{F_C} \simeq -\frac{1}{\sin^2\theta_C}\left(2 - \frac{1 + 9\alpha}{11 + \sigma}\right) \quad , \tag{5}$$

$$\alpha = at^{-1} \quad .$$

If $\alpha=0$, the model predicts an enhancement by a factor of 20 for almost any value of σ. The enhancements occurring in the LPZ and GG models are consequences of charged currents, while in the Bég-Zee model |7| neutral currents are solely responsible for the enhancement |4|

$$\frac{F_{BZ}}{F_C} = 1 - \frac{1}{\sin^2\theta_C} \frac{v}{u} \frac{M_W^2}{M_Z^2 \cos^2\theta_W}$$

$$\simeq 1 - 20\frac{v}{u} \quad . \tag{6}$$

Here u and v are the reduced matrix elements of the non-equivalent tensor operators. Fierz-transformation-based identities |4|, which can be physically questionable, determine the ratio v/u = 1/2, so the enhancement is at least by a factor of 10.

Straightforward analysis of the Salam-Weinberg model, using four quarks only, leads to a very untransparent expression |8| , which can be simplified only under additional assumptions |9|. A theoretically better-founded advance comes through theories using color as a symmetry of strongly interacting gluons |10|. According to ref. |11|, in the product of charged currents, the piece transforming as a 20" representation of SU(4) is enhanced. In the product of neutral currents, the piece transforming as a 15_s representation of SU(4) is enhanced even more. As SU(3) is the symmetry of strong interactions, 20" and 15_s have to be analyzed as to their SU(3) content, which are given by non-equivalent octet tensors T^8 and t^8, respectively. The enhancement is due to neutral currents |8|

$$\frac{F_{SW}}{F_C} = 1 + \frac{1}{\sin^2\theta_C}\left|\frac{1}{2} - \sin^2\theta_W(2 + x)\right| \tag{7}$$

$$x = \langle t^8\rangle / \langle T^8\rangle .$$

Generally, one can expect an enhancement for the $\Delta I=1$ part of the PV potential.

Sum rules of the type (3) hold for the unphysical amplitudes. Extension to the mass shell for nonleptonic hyperon decay amplitudes and simultaneous fit of both s- and p-wave amplitudes require construction of pole models |12|. An additional problem is to make an extension to the off-mass-shell $NN\pi$ amplitude in the case of complex nuclear systems. Some preliminary analyses in this respect have been made |13,12|. There is a hope that γ-circular polarization experiments are not crucially influenced by such effects.

Calculation of the parity-violating NNV (vector-meson) amplitude depends strongly on theoretical methods, as this amplitude, in contrast to the $NN\pi$ amplitude, cannot be at the moment connected with any independently measured experimental quantity. The usage of the factorization approximation |14| is relatively simple and easily adaptable to any H_W model. There are elaborate attempts to found this approximation on current algebra |1|, on which some doubts were recently cast |15|. However, approaches based on $SU(6)_W$ symmetry |16| or the light-cone analysis of intermediate vector-boson (IVB) exchange models |17|, provide persuasive arguments for the importance of nonseparable (nonfactorable) contributions. An example of such a diagram is shown in fig. 2c for a simple gauge-theory model employing only one strong, neutral, massive vector boson R. For a reasonable selection of parameters, separable and nonseparable contributions are comparable |18|. This supports the Pirner-Rustgi approximation illustrated by fig. 3 |19|. A slightly more sophisticated approach is to bind quark lines into vector

mesons |20|. Again, factorable and nonfactorable contributions are comparable. A peculiar PV vector-meson-exchange effect is predicted in the Salam-Pati model |21|, where colored strong vector gluons are mixed with IVB's. The effect is expected to vanish if hadrons are color (i.e., SU(3")) singlets, but it can appear through symmetry breaking.

Multiboson exchanges and exchange effects from weak radiative mesonic transitions have also been considered |22|.

There have been some suggestions to start with the general empirical potential as an input in theoretical nuclear-physics calculations. At most, a semiempiric approach can be attempted where some theory is used to give radial dependence and to limit the number of possible forms and parameters to the manageable one.

Experiments performed so far can be roughly divided as follows:

- circular polarization in γ-emission
- γ- emission asymmetry
- parity-forbidden α decays
- parity violation in N-N scattering.

In the case of complex nuclei, theoretical calculations are very complicated |1,2|. The results obtained using theoretically derived potentials are generally too small, although there are indications that in the venerable case of Ta^{181} the suppression due to short-range correlation and pairing corrections might have been overestimated |23|.

The measured γ-circular polarization P_γ in the two-body problem

$$n + p \rightarrow d + \gamma \qquad (8)$$

was estimated avoiding the perturbational approach. In refs. |24| and |25|, the so-called Danilov |27| approximation was used, which consists in calculating the N-N scattering state first and then finding the deuteron wave function through the analytic continuation. Ref. |28| used the deuteron-nucleon nucleon form factor carrying the calculation partly in the covariant form. Refs. |19,26,29-32| solved the numerically inhomogeneous Schrödinger equation, containing PV potentials. The calculations were performed for a variety of strong N-N potentials, local and nonlocal ones, with hard core and with soft core, including also realistic phase-shift equivalent potentials generated by fixed-range unitary transformations |33|. The results vary in signs and magnitude, lying in the range (depending also on the H_W used)

$$|P_\gamma| < 0.3\cdot 10^{-6} ,$$

which is still almost an order of magnitude smaller than the experimental result |34|

$$P_\gamma = -(1.3 \pm 0.45)\cdot 10^{-6} . \qquad (9)$$

The calculation, as most calculations of P_γ do, involves the difference of two large quantities, so the variety of signs is not surprising.*) On the other hand, it seems that inside a given calculational procedure and for a given PV potential, uncertainties in nuclear physics change the result by less than a factor of two. As P_γ depends on the ΔI=0,2 PV potential, the enhancements (4-7) can be tested only by measuring γ-asymmetry α versus polarized neutrons, where the ΔI=1 contribution is important. However, the theoretical cross section for the process (8) is not quite correct |35|.

*) After discussions, most theorists now agree upon the result $P_\gamma \sim (+)2\cdot 10^{-8}$ |52|.

Estimates |36| indicate that mesonic-exchange current effects are not sufficient to explain the discrepancy. There is a speculation that the continuum $^3S_1$ state is not orthogonal to the bound $^3S_1$ state in the N-N system due to velocity-dependent forces |35|. This can be found out by measuring complicated polarization effects, which do not interfere with α or P_γ measurements. If this is the case, the ΔI=1 PV potential can also contribute to P_γ |37|.

γ-emission-asymmetry experiments have provided the most convincing confirmation of parity violation in nuclei |38|. The recently measured asymmetry of the 110-keV γ ray in ^{19}F |39|

$$\alpha = -(18 \pm 9)\cdot 10^{-5}$$

has resulted in two calculations |40| based on Cabibbo's H_W

$$\alpha = -(6.4 \pm 2.2)\cdot 10^{-5} ,$$

$$\alpha = -(4.2 \pm 1)\cdot 10^{-5} .$$

As both ΔI=0 and ΔI=1 potentials contribute, the enhancement (4-7) of the $NN\pi$ amplitude can obviously help. In connection with this, a measurement of the P_γ for 1.08-MeV photons emitted by ^{18}F, which is expected to be produced by ΔI=1 PV potential, was suggested |41|.

Measurements of parity-violating asymmetry in the cross section of polarized protons on protons |42|

$$\delta = (1 \pm 4)\cdot 10^{-7} \qquad (15\ \text{MeV})$$

and on Be |43|

$$\delta = (5 \pm 9)\cdot 10^{-6} \qquad (6\ \text{GeV/c})$$

have opened a completely new approach to the problem. (We hope strangeness-violating scattering experiments will follow.) Theoretical calculations have also been performed using various H_W's |44|. As p-p scattering receives ΔI=0,1, and 2 PV contributions, it is difficult to understand why it is so small, especially when compared with the result (9). Speculations about the large ΔI=2 (i.e., tensor) component in the PV potential have been put forward |45,51|. This disagrees with octet and singlet dominance |10,11|. It does not contradict the finding for the α decay of the 2^- (8.88-MeV) state of ^{16}O |46|, where the ΔI=0 PV potential is important. It appears that this experimental result is in good agreement with the separable ρ-exchange approximation to Cabibbo's H_W |47|. However, this might be deceptive |48|.

Speculations about the parity-violating NNγ vertex were also attempted |49|.

Despite the apparent confusion, advances have been made in the last few years. In future, theory should strive to improve the calculation of the potentials, especially the ΔI=0,2 part. More precise scattering experiments can be of great help. One should also persevere in trying to measure ΔI=1 transitions |50|.

REFERENCES

|1| E. Fischbach and D. Tadić, Phys. Reports 6C, 124 (1973)

|2| M. Gari, Phys. Reports 6C, 318 (1973)

|3| D. Bailin, A. Love, D.V. Nanopoulos, and G.G. Ross, Nucl. Phys. B59, 177 (1973)

|4| A. Andraši, J. Missimer, and D. Tadić, Phys. Rev. D

|5| J. Prentki and B. Zumino, Nucl. Phys. B47, 99 (1972)
B.W. Lee, Phys. Rev. D6, 1188 (1972)

|6| H. Georgi and S.L. Glashow, Phys. Rev. D7, 561 (1973)

|7| M.A. Beg and A. Zee, Phys. Rev. Lett. 30, 675 (1973)

|8| A. Andraši, J. Missimer, and D. Tadić, Proceedings of the Mainz Symposium 1975

|9| M. Gari and J.H. Reid, Phys. Lett. 53B, 237 (1974)

|10| M.K. Gaillard and B.W. Lee, Phys. Rev. Lett. 33, 108 (1974)

|11| G. Altarelli and L. Maiani, Phys. Lett. 52B, 351 (1974)
G. Altarelli, K. Ellis, L. Maiani, and R. Petronzio, Nucl. Phys. 88B, 213 (1975)

|12| M. Gronau, Phys. Rev. D5, 118 (1972)
M.D. Scadron and L.R. Thebaud, Phys. Rev. D8, 2190 and 2306 (1973)
J. Reid, Nuovo Cimento Lett. 9, 41 (1974)
A. Andraši, B. Eman, J. Missimer, and D. Tadić, Phys. Rev. D

|13| E.M. Henley, T.E. Keliher, W.J. Pardee, and D.U.L. Yu, Phys. Rev. D8, 1503 (1973), D9, 755 (1974)

|14| F.C. Michel, Phys. Rev. 133, B329 (1964)

|37| M. Gari, Proceedings of the Mainz Symposium 1975

|38| E. Kuphal, Proceedings of the Mainz Symposium 1975

|39| E.G. Adelberger et al., Phys. Rev. Lett. 34, 402 (1975)

|40| M. Gari, A.H. Huffman, J.B. McGrory, and R. Offerman, Bochum preprint TP II/105 (1974)
M.A. Box and B.H.J. McKellar, University of Melbourne preprint

|41| M. Gari, J.B. McGrory, and R. Offermann, Phys. Lett. 55B, 277 (1975)

|42| J.M. Potter et al., Phys. Rev. Lett. 33, 1307 (1974)

|43| J.D. Bowman et al., Los Alamos preprint LA-UR 75-405

|44| M. Simonius, Phys. Lett. 41B, 415 (1975) and preprint
V.R. Brown, E.M. Henley, and F.R. Krejs, Phys. Rev. Lett. 30, 770 (1973), Phys. Rev. C9, 935 (1974)
E.M. Henley and F.R. Krejs, Phys. Rev. Lett.
G.N. Epstein, Phys. Lett. 55B, 249 (1975)

|45| B.H.J. McKellar, Saclay preprint DPh.T.75/7 (1975)

|46| K. Neubeck, H. Schober, and H. Wäffler, Phys. Rev. C10, 320 (1974)

|47| M. Gari, Phys. Lett. 31B, 627 (1970)
M. Gari, J.G. Zabolitsky, and H. Kümmel, Nucl. Phys. A161, 625 (1971)
E.M. Henley, T.E. Keliher, and D.U.L. Yu, Phys. Rev. Lett. 23, 941 (1969)
W.K. Cheng, E. Fischbach, H. Primakoff, D. Tadić, and K. Trabert, Phys. Rev. D3, 2289 (1971)

|48| M. Simonius, Nucl. Phys. A220, 269 (1974)
G. Fai, B. Apagyi, and J. Nemeth, Debrecen Triangular Seminar 1974

|49| E.M. Henley, A.H. Huffman, and D.U.L. Yu, Phys. Rev. D7, 943 (1973)
L. Wolfenstein, Nucl. Phys. B72, 111 (1974)

|50| E. Bellotti, E. Fiorini, P. Negri, A. Pullia, L. Zanotti, and I. Filosofo, Milano preprint 1975

|51| M. Simonius, Proceedings of the Mainz Symposium 1975

|52| B.H.J. McKellar, private communication

|15| M.A. Perez, CIEA, México preprint

|16| B.H.J. McKellar and P. Pick, Phys. Rev. D7, 260 (1973); D6, 2184 (1972)

|17| G.S. Danilov, Nucl. Phys. B60, 221 (1973)
B. Guberina, J. Missimer, and D. Tadić, Phys. Rev. D9, 2456 (1974)

|18| H. Galić, B. Guberina, and D. Tadić, Proceedings of the Mainz Symposium 1975

|19| H.J. Pirner and M.L. Rustgi, Stony Brook preprint 1975

|20| M.K. Sundersan and P.J.S. Watson, Ann. of Phys. 59, 375 (1970)
M. Böhm, H. Joos, and G. Krammer, Nucl. Phys. 51B, 397 (1973)
D. Flamm, P. Kielanowski, and J. Sánchez Guillén, Nuovo Cimento A25, 16 (1975)

|21| J.C. Pati and A. Salam, Phys. Rev. D8, 1240 (1973); D10, 275 (1974), Phys. Rev. Lett. 34, 613 (1975)

|22| R. Lacaze, Nucl. Phys. B4, 657 (1968)
B. Desplanques, Phys. Lett. 41B, 461 (1972)
H.J. Pirner and D.O. Riska, Phys. Lett. B44, 451 (1973)
M. Chemtob, B. Desplanques, Nucl. Phys. B78, 139 (1974)
E.M. Henley, Phys. Rev. Lett. 27, 542 (1971) and Phys. Rev. C7, 1344 (1973)
P. Herczeg and P. Singer, Phys. Rev. D

|23| J. Missimer, A.D. Jackson, and E. Fischbach, Nucl. Phys. A290, 221 (1973)
B. Desplanques, private communication

|24| G.N. Epstein, Oxford University preprints (1974, 1975)

|25| K.R. Lasey and B.H.J. McKellar, Lett. Nuovo Cimento 11, 161 (1974)
Aust. J. Phys. 27, 637 (1974)

|26| K.R. Lasey and B.H.J. McKellar, University of Melbourne preprint

|27| G.S. Danilov, Phys. Lett. 18B, 40 (1965), Phys. Lett. 35B, 579 (1971), Soviet J. Nucl. Phys. 14, 443 (1972)

|28| J. Micheli and D. Pignon, Orsay preprint

|29| M.L. Rustgi and H.J. Pirner, Phys. Rev. 10C, 2099 (1974)

|30| B. Desplanques, Orsay preprint IPNO/TH 74-38

|31| Y.E. Kim, Purdue University preprint

|32| E. Hadjimichael and E. Fischbach, Phys. Rev. D3, 755 (1971)

|33| T. Hamada and J.D. Johnston, Nucl. Phys. 34, 382 (1962)
H. Feschbach and E. Lomon, Rev. Mod. Phys. 39, 611 (1967)
R. de Toureil and D.W.L. Sprung, Nucl. Phys. A201, 193 (1973)
K.E. Lassila et al., Phys. Rev. 126, 881 (1962)
R.V. Reid, Ann. of Phys. 50, 411 (1968)
J.P. Vary, Phys. Rev. C7, 521 (1973)
T.R. Mongan, Phys. Rev. 178, 1597 (1969)

|34| V.M. Lobashov et al., Nucl. Phys. A197, 241 (1972)

|35| Proceedings of the Asilomar Conference (ed. B.L. Berman, Oak Ridge 1973)
Proceedings of the Mainz Symposium 1975
G. Breit and M.L. Rustgi, Nucl. Phys. A161, 337 (1971)
B. Bosco, private communication

|36| E. Hadjimichael, Phys. Lett. 46B, 147 (1973)
A.D. Jackson and D.O. Riska, Phys. Lett. 50B, 207 (1974)
A.D. Jackson, A. Lande, and D.O. Riska, Phys. Lett. 55B, 23 (1975)

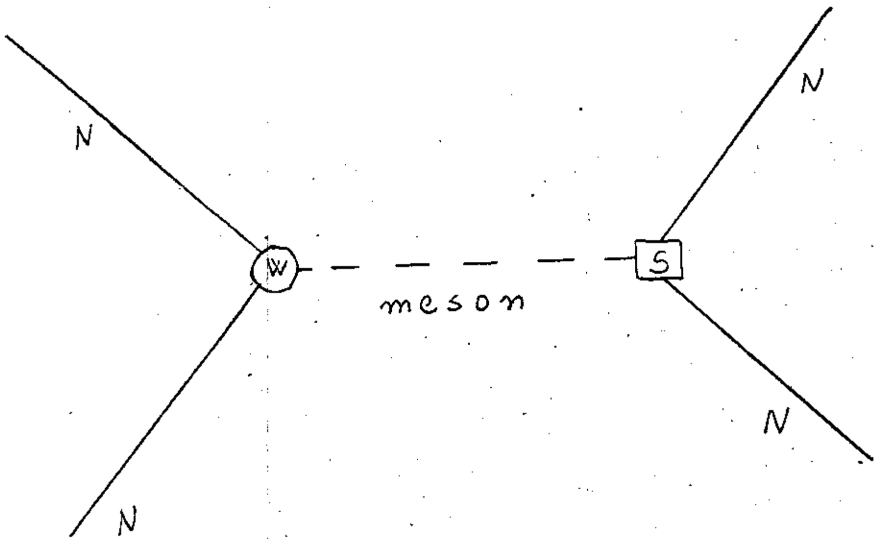

Fig. 1

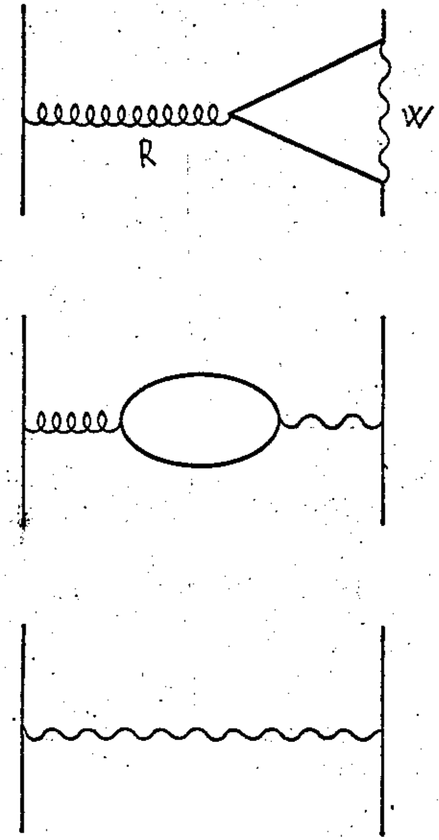

Fig. 2

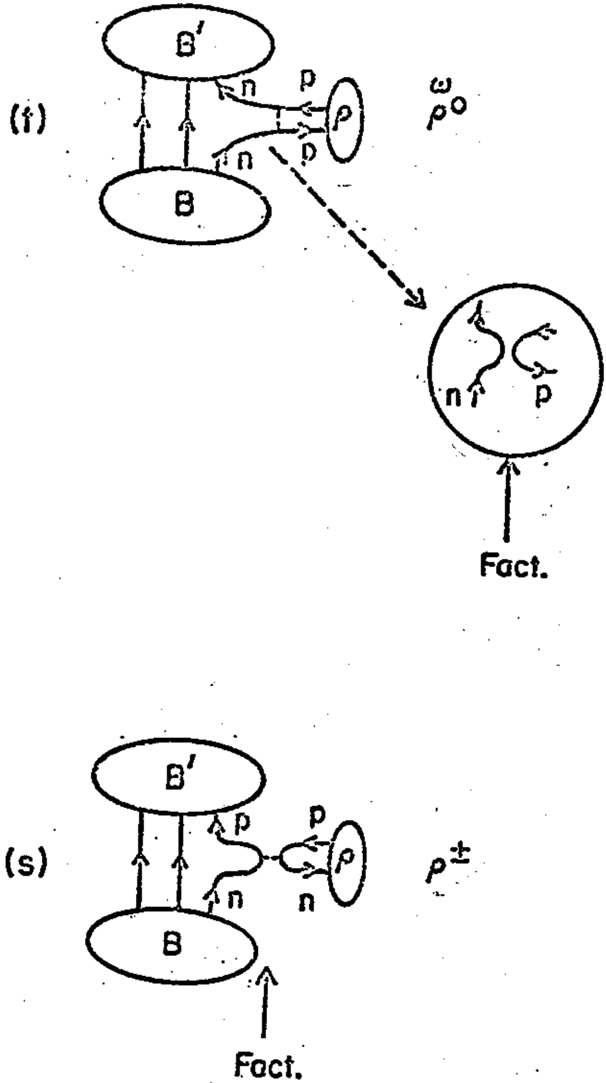

Fig. 3.