# PARITY VIOLATION IN NUCLEI

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## INTRODUCTION

Nuclear parity violation[1] provides a window on a part of the hadronic weak interaction which is otherwise invisible. The idea of a universal weak current which acts in hadrons as well as leptons is of course central to all modern theories of the electroweak force but it is one which does not readily admit testing. We have some experimental knowledge of $\Delta S=1$ and $\Delta C=1$ non-leptonic weak processes, and there is little cause for satisfaction in our understanding of those processes. The only immediate prospect for probing the $\Delta S=0$ interaction is nuclear parity violation, and in the early days it was hoped that much of a fundamental nature might be learned. This optimism soon yielded to gloom when the cluttered nature of the nuclear workshop became apparent. Now, following substantial efforts both by theorists and experimentalists there is a renewed, more conservative optimism that nuclear parity violation (PV) can be understood at a level which tests our ability to calculate hadronic interactions, although it is not likely to influence the development of the underlying theories of the weak interaction.

## THE TWO-NUCLEON SYSTEM

For obvious reasons, the two-nucleon system is an interesting one and we now have the remarkable luxury of not one but four

*Present address

successful observations of parity violation in the scattering of polarized protons by nucleons. At 15 MeV the Los Alamos collaboration has observed a difference in the cross-section for the scattering of longitudinally-polarized protons from hydrogen for the two helicities of the beam. After lengthy and careful analysis (still in progress) of possible systematic effects, the result of Potter et al.[2] is

$$A_{pp} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = (-1.2 \pm 0.6) \times 10^{-7} \quad .$$

The second measurement of this quantity has been made at the Sweizeriches Institut für Nuklearforschung using a 45 MeV polarized proton beam from the SIN injector cyclotron. The experimenters find[3]

$$A_{pp} = (-2.3 \pm 0.8) \times 10^{-7}.$$

The third measurement is not strictly a measurement of the quantity $A_{pp}$. Lockyer et al.,[4] using the 5 GeV polarized proton beam from the Argonne ZGS, measured the helicity-dependence of the transmission through a water target. They find an extremely large effect,

$$\bar{A}_{pN} = (+2.6 \pm 0.6) \times 10^{-6}.$$

In their new apparatus, a low-dispersion spectrometer removes hyperon decay products which, in earlier versions of the experiment, produced large asymmetries. The main systematic effect now (about $+1.8 \times 10^{-6}$) results from passage of the beam through air and some monitoring equipment while its polarization is still transverse.

The fourth result is also a transmission measurement and is now in progress at LAMPF by the same group that carried out the 15 MeV measurement. At 800 MeV they find [5]

$$\bar{A}_{pN} = (+3.0 \pm 1.0) \times 10^{-6},$$

also a much larger effect than expected. Both the 5 GeV and 800 MeV results are to be considered very preliminary.

Figure 1 shows the 4 measurements in a log-log plot to illustrate that the high energy results, while large, are not totally at variance with the trend of the low energy data. Of course, there is a sign difference, and the quantities being measured are not strictly the same. In the more detailed theoretical analysis of Henley and Krejs,[6] the higher energy data are at least an order of magnitude larger than expected. The solid curve in the figure has the energy dependence given by Brown, Henley and Krejs[7] and Henley and Krejs,[6] and is normalized in a manner I will describe later.

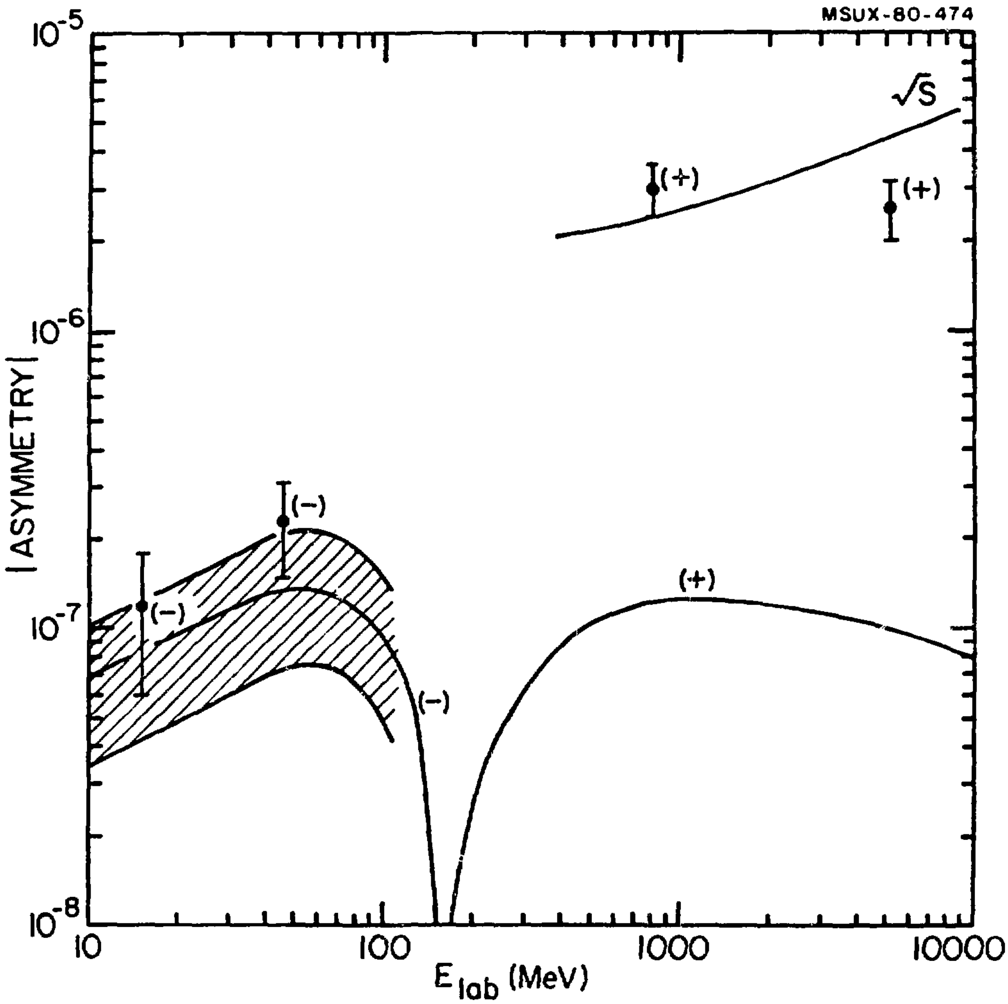


Fig.1 Plot of parity-violating asymmetries observed in polarized proton scattering. The signs of the measurements and of the theoretical curve are indicated.

There is real significance in the fact that the two lower energy points lie on a line of slope 1/2, because the asymmetry at low energies depends simply on the amplitude for mixing from S-to P-states, which in turn is proportional to the momentum. The importance of this agreement cannot be exaggerated because it implies that two separate, very difficult experiments performed on different accelerators by different groups of physicists are measuring the same quantity.

At higher energies, as shown by Simonius,[8] the theoretical curve turns over and eventually passes through zero at about 150 MeV because of a cancellation in the strong interaction phase shifts. Above 300 MeV the analysis becomes vastly more difficult, at least in the inclusive type of experiment, because of the opening of inelastic channels. Below 300 MeV the magnitude of the asymmetry $A_{pp}$ depends on all 3 isospin components of the weak force, $\Delta T=0$, 1 and 2, although it is not influenced by the long-range pion exchange allowed by neutral currents, since (by Barton's theorem[9]) only charged pions contribute in a CP-conserving interaction. At higher energies the asymmetry might be expected to scale as the square root of the invariant c.m. squared energy, s, if there were no damping of the incident waves through absorption; theory suggests substantial absorption.

Radiative capture in the n-p system also provides information of a rather basic nature. As was shown by Danilov,[10] a measurement of the circular polarization of $\gamma$ rays emitted in thermal neutron capture by protons is sensitive only to the $\Delta T=0,2$ parts of the force, while the directional asymmetry of $\gamma$ rays from capture of polarized neutrons is sensitive to the $\Delta T=1$ part.

The circular polarization has been measured in a celebrated experiment by Lobashov's group[11] (Fig. 2). As is well known, they

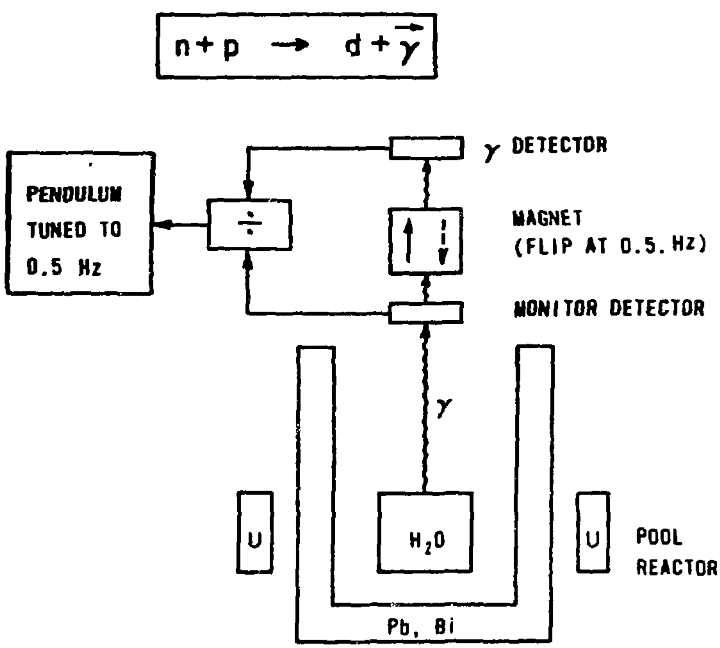


Fig. 2 Schematic diagram of experiment of Lobashov et al. (Ref. 11).

find a result $P_\gamma = (-1.3 \pm 0.5) \times 10^{-6}$, a value which, despite intensive theoretical effort, has not been satisfactorily explained. As McKellar[12] has pointed out, there is in this case a spectacular cancellation between the parity violating effects in the initial and final states, a cancellation which is not sensitive to the potentials chosen to describe the states. Thus all calculations which proceed from first principles or from parameterization of other data fail by a factor of 100 or so to give the observed effect.

In view of the importance of this result, there is considerable interest in confirming it. Two experiments are in preparation. At Chalk River, McDonald, Earle and Knowles[13] are setting up the inverse experiment, (Fig. 3) in which the deuteron is photodisintegrated with circularly polarized bremsstrahlung. Lee[14] has shown that, even for photons well above threshold, this reaction measures the same thing as the Lobashov experiment. Circularly polarized bremsstrahlung are produced from longitudinally polarized electrons. A SLAC-type GaAs source[15] and 4 MV linac are used.

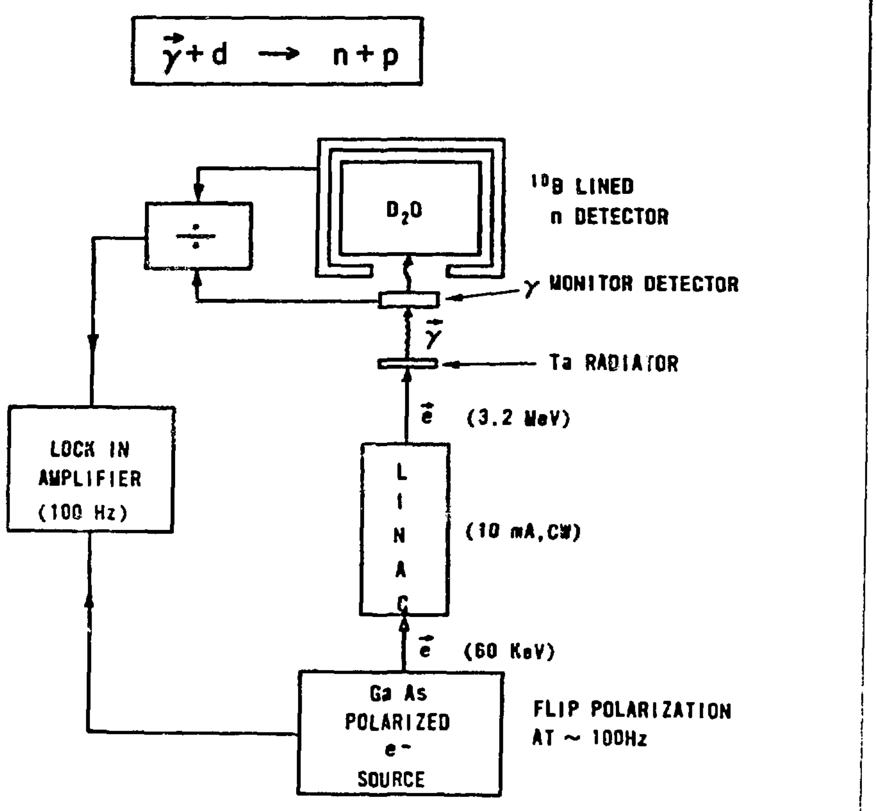


Fig. 3 Schematic diagram of deuteron photodisintegration experiment of McDonald et al. (Ref. 13).

Lisowski and Bowles[16] are investigating the possibility of using the intense neutron pulses available at the LAMPF Neutron Research facility. The unique time structure would permit detailed study of the circular polarization of the signal and the background (Fig. 4). It will be recalled that circularly polarized bremsstrahlung from β activities was one of the major concerns of the Lobashov group in their reactor-based experiment.

For the time being theorists are pragmatically omitting the Lobashov result from their analyses because, if it is right, theory needs such radical revision that current analyses are incorrect, and, if it is wrong, there is no point in including it.

## ΔT=1 PARITY VIOLATION

Let us turn now to one of the most interesting aspects of nuclear PV studies, the question of whether there is a parity-violating hadronic neutral current interaction. In the absence of

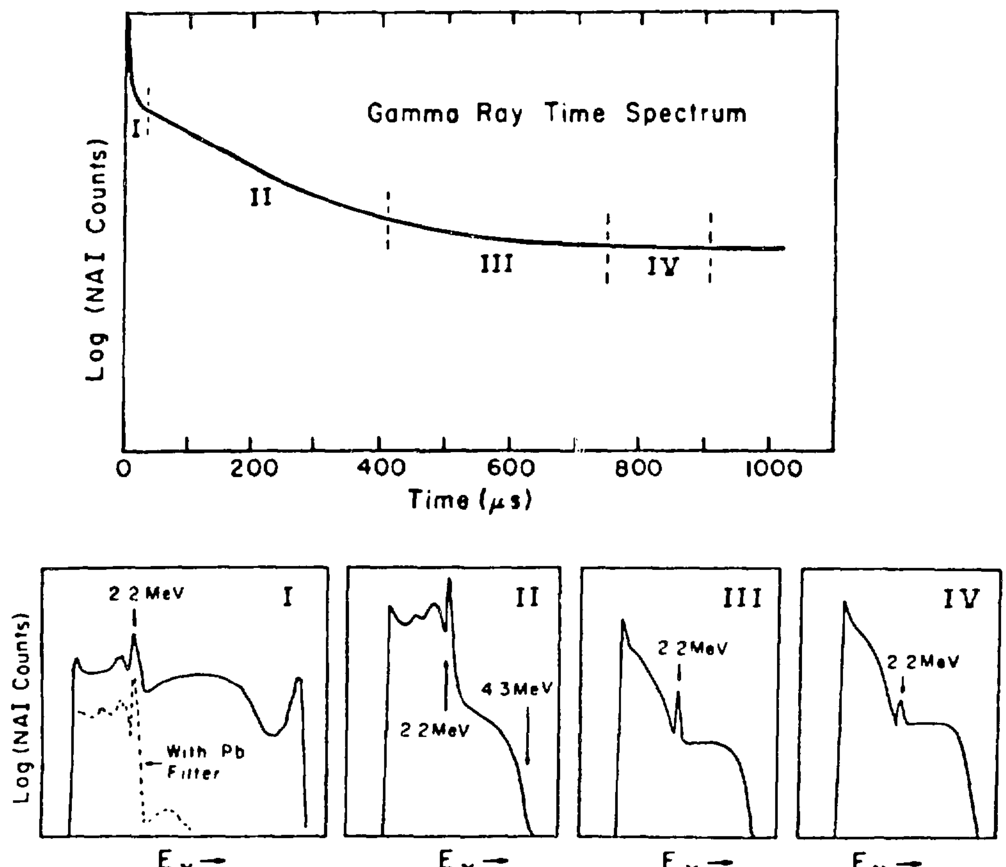


Fig. 4 Time structure of γ-rays following beam burst, and corresponding γ-spectra (Ref. 16).

neutral currents (n.c.) the $\Delta T=1$ components in the Hamiltonian arise only from strangeness-changing currents and are Cabibbo-suppressed by the factor $\sin^2\theta_C$, about 0.052. If, in addition, a n.c. acts, then isovector parity violation may not be so suppressed (the term "enhanced" is sometimes used to describe this situation!).[17] However, the uncertainties in the n.c. part of the effective weak Hamiltonian are so large that one can only say that the presence of an isovector enhancement definitely indicates parity-violating hadronic neutral currents, while its absence is merely inconclusive. It is convenient to define an enhancement factor F which is the ratio of actual isovector parity-irregular amplitude in a nuclear wavefunction to that expected from charged currents alone.

Nature has been parsimonious in providing examples where $\Delta T=1$ PV might be observed in isolation. In fact only 4 cases satisfy the twin constraints of experimental and theoretical tractability.

$\vec{n}+p\ d+\gamma$

The two-nucleon system is the most amenable to theoretical treatment, and for $\Delta T=1$ does not suffer from the cancellations that render the $\Delta T=0,2$ parts so small and uncertain. Even so, the expected effect[18] is exceedingly small, a $\gamma$-ray asymmetry $A_\gamma$ of 7F x $10^{-9}$. Cavaignac, Vignon and Wilson[19] have performed an experiment at the Institut Laue-Langevin using a liquid $D_2$ moderator, Fe-Co mirror neutron polarizer, a liquid para-$H_2$ target and scintillators to detect the $\gamma$ rays. Their result,

$$A_\gamma = (0.6\pm2.1) \times 10^{-7},$$

sets an upper limit of about 40 on the enhancement factor. A new version of the experiment with improved neutron polarization and intensity, and better geometry and light collection from the scintillators, is planned. An accuracy of 2 to 3 x $10^{-8}$ could be attained.[20]

$^6Li(3.56)\rightarrow \alpha+d$

The alpha decay of the $0^+$,T=1 state of $^6Li$ is energetically allowed but forbidden by both parity and isospin conservation. Many attempts have been made to observe this process (or, more commonly, the corresponding $\alpha$+d capture through the 3.56 MeV state), with the experiment of Bellotti et al.[21] achieving the highest sensitivity. Using a gas cell containing $D_2$, a $^4He$ beam, and a Ge(Li) detector to search for capture $\gamma$ rays through the $0^+$, T=1 state, they were able to set an upper limit of $8\times10^{-4}$ eV on the parity forbidden alpha width $\Gamma_{\alpha d}$.

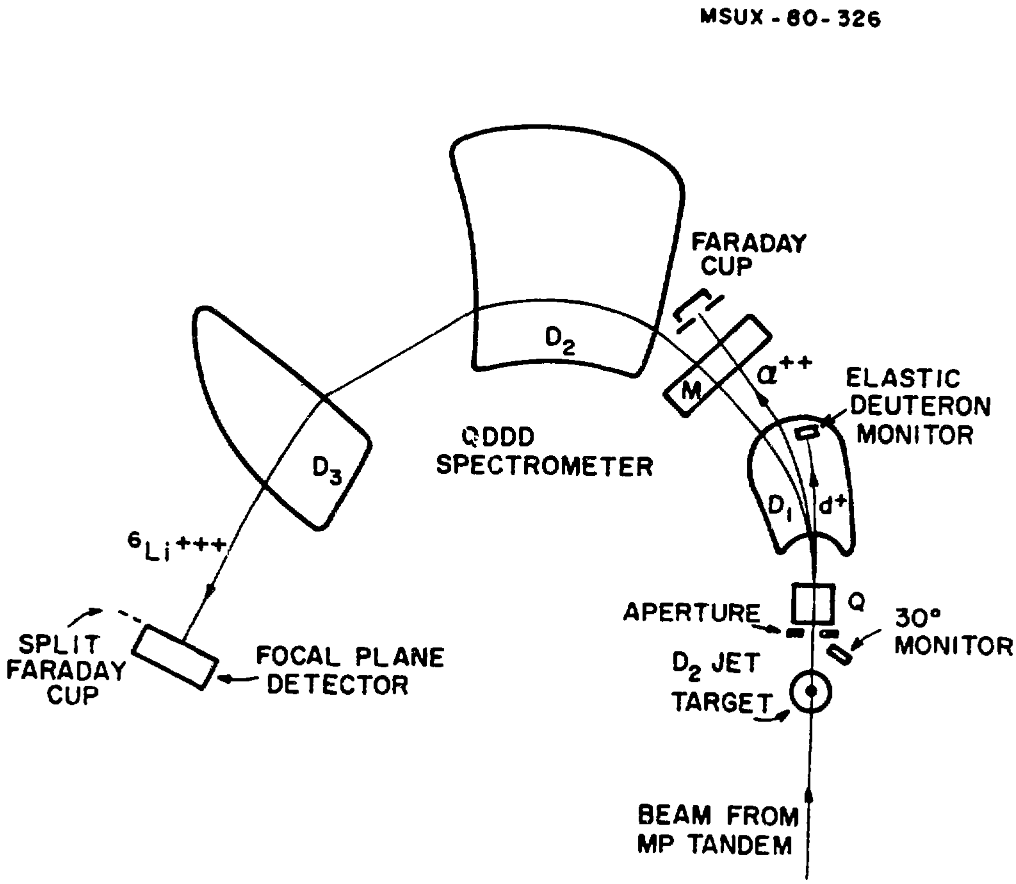


Fig. 5 Apparatus used for direct detection of $^6$Li recoils from the $^2H(\alpha,\gamma)$ reaction.

A Michigan State-Argonne-Chalk River collaboration[22] is engaged in a new experiment to improve on this limit. Rather than detecting $\gamma$ rays, we use a windowless $D_2$ jet target and detect $^6Li^{+++}$ ions directly on the focal plane of a large magnetic spectrograph (QDDD type) (Fig. 5). In this way $^6$Li produced by direct (non-resonant) capture has been observed for the first time at the 20nb level, virtually free of background. Figure 6 shows the $a_0$ term (the isotropic component of the angular distribution) plotted as a function of beam energy. The solid curve is a Gaussian peak of predetermined width fitted for amplitude and position on a constant background. From these data we concludethat $\Gamma_{\alpha d}=(0.6\pm0.8)\times10^{-6}$ eV, and $\Gamma_{\alpha d} \leq 2\times10^{-5}$ eV (90% C.L.).

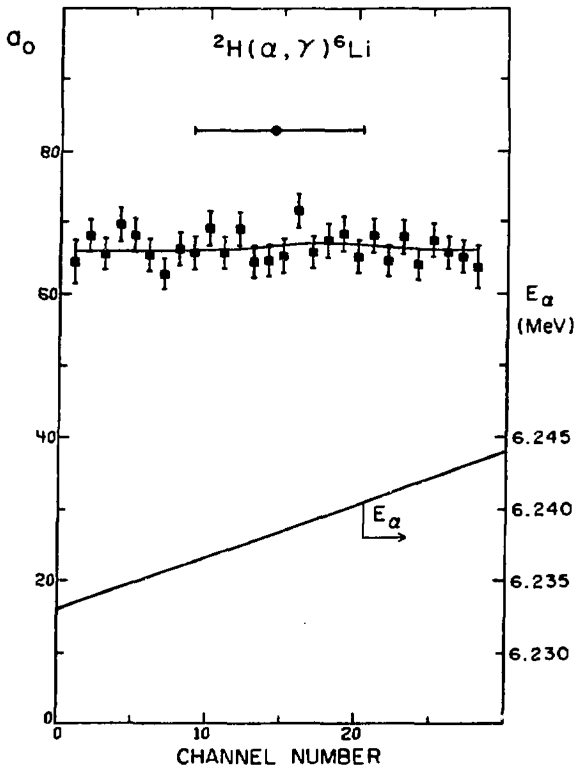


Fig. 6 Excitation function of isotropic component of $^2H(\alpha,\gamma)^6Li$ reaction. The expected resonance position is indicated by the horizontal bar.

No detailed theoretical treatment of this case has been presented in the literature. It is unusual in a nuclear PV context because the parity impurity occurs in an isolated state embedded in the continuum rather than as an admixture between two close-lying levels. Michel[23] presented a simple theorem which lends itself to this problem. If the full effective Hamiltonian is of the form

$$H = H_o + G\ \vec{\sigma}\cdot\vec{p}$$

where $H_o$ is the unperturbed Hamiltonian and $G\ \vec{\sigma}\cdot\vec{p}$ a one-body parity violating effective potential, then, to second order,

$$H = e^{-iS}\ H_o e^{iS}$$

where $\hbar S = m_N G\ \vec{\sigma}\cdot\vec{r}$. The perturbed wavefunctions may thus be obtained directly by the transformation

$$\psi_i = e^{-iS}\psi_i^{(o)} = [\, 1 - im_N \hbar^{-1} G\, \vec{\sigma} \cdot \vec{r}\,]\, \psi_i^{(o)} \;,$$

in an obvious notation. One may thus proceed directly from unperturbed to parity-irregular wavefunctions without introducing any dubious unknown $0^-$,T=0 levels at high excitation. Robertson and Riska,[24] using a Vergados[25] shell-model wavefunction for $^6$Li, and treating also the parity violating component of the deuteron wavefunction, have calculated $\Gamma_{\alpha d} = 3.4\ F^2 \times 10^{-10}$ eV. Thus the limit on F from experiment is about 30. However, this is a very schematic calculation which uses harmonic oscillator wavefunctions, neglects the parity impurity in the alpha particle, treats only weak $\pi$ exchange, neglects core excitations, etc., so a more refined calculation could well give a significantly different result.

$^6$Li $+ \alpha \rightarrow$ $^{10}$B(5.164)

A pair of levels in $^{10}$B, the 5.110 MeV $2^-$,T=0 and 5.164 MeV $2^+$, T=1 states, provides the basis for an extremely sensitive search for neutral currents.[26] An experiment is now in preparation at Argonne[27] in which a polarized $^6$Li target is formed on a heated oxygenated W surface (Fig. 7). This target is bombarded with 1.2 MeV $\alpha$ particles (to excite the 5.16 MeV state) and parity violation is evidenced by a dependence of the total capture cross section on the vector polarization of the $^6$Li:

$$\sigma_{\alpha\gamma} = \sigma_o (1 - \alpha RP + \frac{A}{2}) ,$$

where P is the longitudinal vector polarization (i.e., $m_{+1} - m_{-1}$), A the tensor polarization ($1-3m_o$), $\alpha$ the parity mixing amplitude

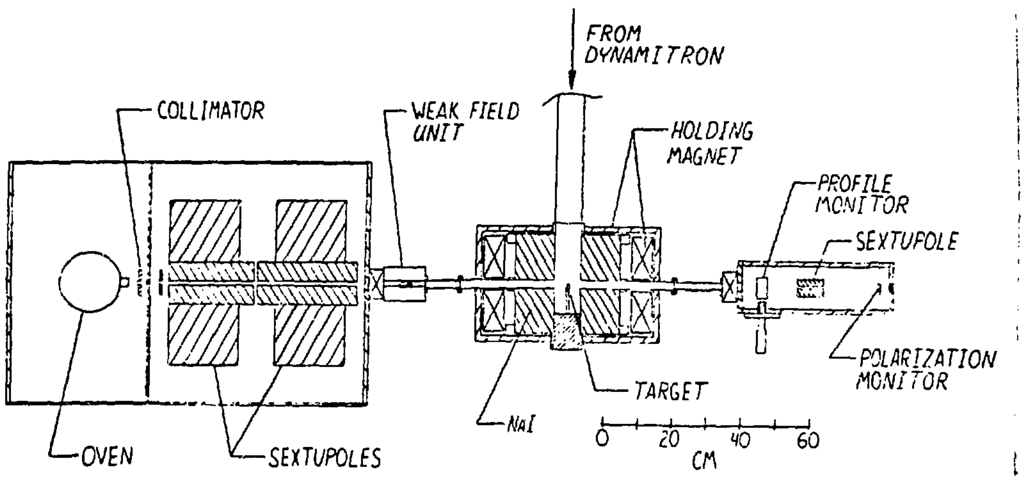


Fig. 7 Atomic beam apparatus for production of polarized $^6$Li target.

$\langle 2^+|H_{PV}|2^-\rangle/\Delta E$ and R a structure enhancement which depends on the relative alpha widths and penetrabilities for the two states.

$$R = 3\sqrt{\frac{3}{5}}\left[\frac{\Gamma_{\alpha(2^-)}}{\Gamma_{\alpha(2^+)}}\right]^{1/2}\left[\frac{P_\alpha(5.164)_{L=1}}{P_\alpha(5.110)_{L=1}}\right] \simeq 105.$$

A preliminary estimate for the mixing matrix element, including only the long-range $\pi$ exchange part of the $\Delta T=1$ force, has been made by Teeters and Kurath,[28] who find

$$\langle 2^+|H_{PV}|2^-\rangle \simeq 0.036\ F\ \ eV .$$

It is anticipated that the experiment will actually be able to probe to the level $F \approx 1$.

<u>$^{18}F(1.081) \rightarrow {}^{18}F+\vec{\gamma}$</u>

The best direct limit on isovector parity violation yet obtained comes from the doublet of states in $^{18}F$, the $0^+$,T=1 level at 1.042 MeV and the $0^-$,T=0 level at 1.081 MeV. Parity mixing between these close-lying states gives rise to a circular polarization in the $\gamma$ ray de-exciting the relatively long-lived 1.081 MeV state. Since the first measurement of this quantity by the Caltech-Seattle-Cal State Los Angeles collaboration[29] there have been two new attempts, one by Waffler's group at the Max-Planck-Institut für Chemie, Mainz,[30] and the other by Maurenzig et al. at Florence.[31] Data from the Mainz experiment are shown in Fig. 8. None of the experiments finds a non-zero circular polarization. (It is curious that two[29,30] seem to show positive effects for the 1.02 MeV transition which feeds the 1.081 MeV level from above. This may be simply an artifact associated with summing of 511-keV annihilation quanta at this energy.) The three measurements and their weighted average are summarized in Table 1. As will be discussed later, this limit severely restricts the possible range of neutral current enhancement in nuclei.

Table 1. Measurements of circular polarization of 1.081 MeV $\gamma$-rays in $^{18}F$.

| Reference | Result x $10^3$ |
|---|---|
| 29 (Barnes et al.) | $-0.7 \pm 2.0$ |
| 30 (Wäffler) | $+0.8 \pm 1.8$ |
| 31 (Maurenzig et al.) | $-1.0 \pm 3.0$ |
| Average | $-0.1 \pm 1.2$ |

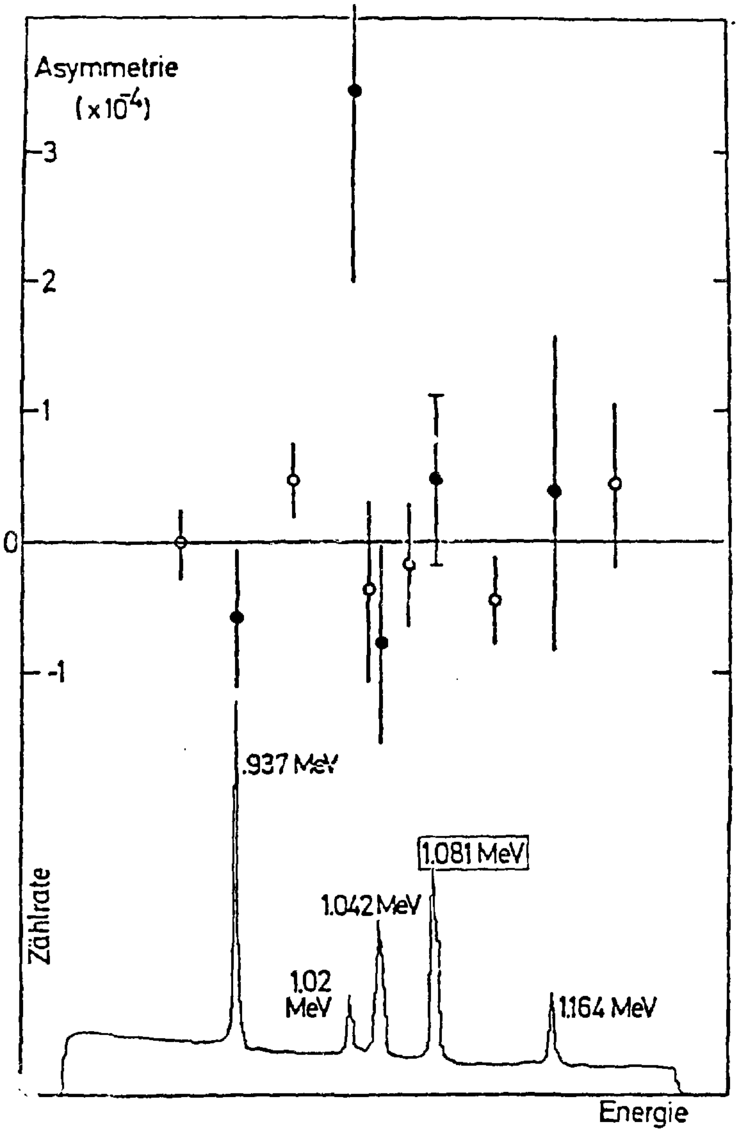


Fig. 8 Gamma spectrum from $^{16}O(^{3}He,p)^{18}F$ reaction and experimental "asymmetries" for various spectral regions. The circular polarizations are proportional to these asymmetries. (Ref. 30).

We conclude this section with the observation that there is no prima facie case for $\Delta T=1$ nuclear parity violation, but, as we shall describe, recent experimental and theoretical work in mass 18, 19 and 21 lead to a rather well-defined and startling result.

## THEORETICAL CONSIDERATIONS

Proceeding from a fundamental weak interaction theory to experiment is now seen to be an extremely complicated task, involving detailed nuclear structure, short range correlations, an effective weak Hamiltonian and symmetry principles. Recently some new approaches have been developed which have been very valuable in pinpointing problem areas in theory and experiment. McKellar and collaborators and Desplanques and Missimer have pioneered techniques which allow a critical assessment of whether the existing experimental data are internally consistent, and whether or not one can, even in principle, hope to understand the data in terms of a fundamental theory. McKellar[12] has started with a general set of spin-isospin effective operators and has assumed a meson exchange form of weak potential in order to parameterize existing data. Desplanques and Missimer[32] have avoided the meson exchange picture by making use of the low-energy weak scattering amplitudes as fundamental parameters. The advantage is a more model-independent synthesis of all the data, but the price paid is the remote connection between weak interaction theory and the scattering amplitudes. Both of these approaches have led to two important conclusions: a) The large result from the Lobashov experiment[11] cannot be accommodated without radical changes in the theory, and , b) Until this year the isovector components were essentially undetermined.

Two theoretical advances of the highest significance have occurred this year. Desplanques, Donohue and Holstein[33] (DDH), recognizing that symmetry principles by themselves are non-predictive, incomplete or inapplicable, have combined the $SU(6)_W$ symmetry for non-leptonic weak decays with a quark model to arrive at a detailed description of the weak nucleon-nucleon meson couplings. They conclude that strong interaction uncertainties make it impossible to assign definite values to the weak NNm couplings but that the strengths are, with high probability, constrained to be within well-defined limits. In the non-relativistic limit, DDH parameterize the NN PV potential in terms of $\pi$, $\rho$ and $\omega$ exchange, decomposed according to isospin exchange character. The ranges allowed for the coupling constants are listed in Table 2.

The remaining part of the problem has been tackled by Haxton, Gibson and Henley[34] and by Brown, Richter and Godwin[44] in full two-body shell model calculations for three nuclei near mass 20. The $\Delta T=1$ $^{18}$F experiments have already been mentioned; the others are a measurement of the $\gamma$-ray asymmetry in the decay of polarized $^{19}$F in its $1/2^-$, 110 keV state to the ground state (Adelberger et al.,[35] $A_\gamma = -8.5(26)\times10^{-5}$); and a measurement of the circular polarization of the $\gamma$-ray de-exciting the $1/2^-$ 2.79 MeV state in $^{21}$Ne to the ground state (Snover et al.,[36] $P_\gamma = +2.3(29)\times10^{-3}$). The last two

Table 2. Probable ranges for NNm coupling constants (Ref. 33).

| Parameter* | Cabibbo | Weinberg-Salam |
|---|---|---|
| $f_\pi^a$ | 0 to 1 | 0 to 30 |
| $h_\rho^0$ | 15 to -64 | 30 to -81 |
| $h_\rho^1$ | 0 to -0.7 | -1 to 0 |
| $h_\rho^2$ | -58 | -20 to -29 |
| $h_\omega^0$ | 6 to -22 | 15 to -27 |
| $h_\omega^1$ | 0 to -2 | -5 to -2 |

*In units of $3.8 \times 10^{-8}$ ($h=m_n=c=1$)

[a] $F = f_\pi / 3.8 \times 10^{-8}$

measurements, being in T =-1/2 nuclei, are influenced both by $\Delta T=0$ and 1 parts of the PV interaction. However, since $^{19}F$ is an odd-proton nucleus and $^{21}Ne$ an odd-neutron nucleus, it might be expected that the $\Delta T=0$ and 1 pieces would have different relative signs if the wave functions were the same. In fact, the states involved are not that simply related, but a separation of the two components indeed occurs. Thus the recent $^{21}Ne$ experimental result, even though null, is extremely important because it can only vanish by virtue of a cancellation between the $\Delta T=0$ and 1 parts of the interaction.

The three observations can be expressed in terms of PV mixing matrix elements $\langle H_{pv} \rangle$ (all three are accurately two-state mixing cases; $\langle H_{pv} \rangle$ is in eV):

$$^{18}F \qquad P_\gamma = 4.9 \times 10^{-3} \langle H_{PV}^{18} \rangle$$

$$^{19}F \qquad A_\gamma = 2.0 \times 10^{-4} \langle H_{PV}^{19} \rangle$$

$$^{21}Ne \qquad P_\gamma = 9.5 \times 10^{-2} \langle H_{PV}^{21} \rangle$$

These mixing matrix elements are then expressible in terms of the weak coupling constants of DDH as follows:

$$0.0862\ f_\pi^1 = \langle H_{PV}^{18} \rangle$$

$$0.0546\ f_\pi^1 - 0.0197\ (h_\rho^o + 0.56h_\omega^o) = \langle H_{PV}^{19} \rangle$$

$$-0.0310\ f_\pi^1 - 0.0124\ (h_\rho^o + 0.56h_\omega^o) = \langle H_{PV}^{21} \rangle\ .$$

where $f_\pi^1 = f_\pi - 0.12h_\rho^1 - 0.17h_\omega^1$.

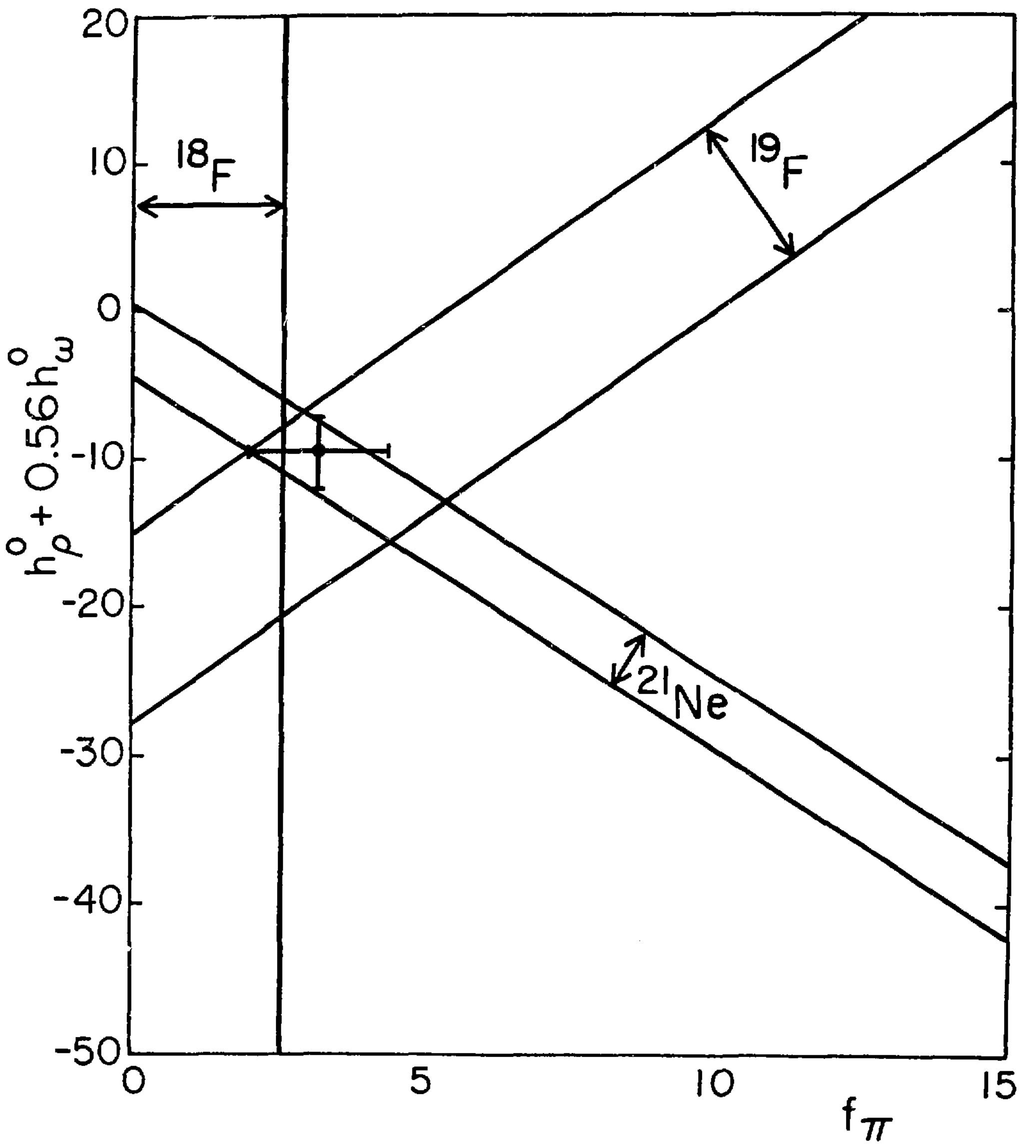


Fig. 9 Dependence of parity violation in $^{18}$F, $^{19}$F and $^{21}$Ne on isoscalar and isovector parts of weak force.

The equations are plotted in Fig. 9. We find

$$h^{o}_{\rho} + 0.56h^{o}_{\omega} = -9.4\pm2.7$$

and $f^{1}_{\pi} = 3.2\pm1.1$ with $\chi^{2} = 1.2$.

Allowing $h^{1}_{\rho}$ and $h^{1}_{\omega}$ to span the full range given by DDH adds an additional $\pm0.3$ uncertainty to $f_{\pi}$, and the result is

$$f_{\pi} = 2.5\pm1.1.$$

This small a value for $f_{\pi}$ is quite remarkable. Bearing in mind that charged currents alone give values for $f_{\pi}$ between 0 and 1, we find little, if any, evidence for hadronic neutral current parity violation.[45]

The isoscalar term is also somewhat smaller than expected. We may test its reliability by referring back to the proton-proton scattering experiments. DDH give for the asymmetry at 15 MeV,

$$A_{pp} = 0.0837(h^{o}_{\omega} + h^{1}_{\omega} + h^{o}_{\rho} + h^{1}_{\rho} + h^{2}_{\rho}/\sqrt{6}).$$

Inserting the value obtained for $h^{0}_{\rho} + 0.56h^{0}_{\omega}$ and allowing the remaining undetermined parameters to vary (coherently) over the full range specified by DDH, one finds the normalization used for the solid curve in Fig. 1 and the possible variation indicated by the shaded area. The agreement is excellent and further increases one's confidence in the detailed and careful analyses made by Haxton et al. and by Brown et al.

## CONCLUSIONS

A summary of parity violating effects in nuclei is given in Table 3. Not included in this table are the novel neutron spin rotation measurements in tin isotopes performed by Forte et al.[37] and the observations of parity violating effects in the fission of $^{233}U$, $^{235}U$ and $^{239}Pu$ by polarized neutrons.[38] Also omitted are some null results in heavier nuclei. Tadic[1] and Gari[17] give keys to the literature.

Thanks to vigorous experimental and theoretical effort, it now appears that a reasonably well-defined value for the weak isovector π-nucleon coupling constant can be obtained. There is one major uncertainty in the analysis, namely the M2/E1 mixing ratio for the 2.79 MeV transition in $^{21}Ne$. This quantity is virtually impossible to calculate reliably and must be measured. If it turns out to be much larger than 1, then a null result in $^{21}Ne$ is expected no matter

Table 3. Parity violation in nuclei

| Reaction | ΔT | Result | References |
|---|---|---|---|
| $n + p \to d + \gamma$ | 0,2 | $P_\gamma = -1.3(5) \times 10^{-6}$ | 11 |
| $\vec{n} + p \to d + \gamma$ | 1 | $A_\gamma = 0.6(21) \times 10^{-7}$ | 19 |
| $\vec{p} + p \to p + p$ (15) | 0,(1),2 | $A_L = -1.2(6) \times 10^{-7}$ | 2 |
| $\vec{p} + p \to p + p$ (45) | 0,(1),2 | $A_L = -2.3(8) \times 10^{-7}$ | 3 |
| $\vec{p} + N \to X$ (800) | 0,1,2 | $A_L = +3.0(10) \times 10^{-6}$ | 5 |
| $\vec{p} + N \to X$ (5000) | 0,1,2 | $A_L = +2.6(6) \times 10^{-6}$ | 4 |
| $\vec{n} + d \to t + \gamma$ | 0,1,2 | $A_\gamma = +6.5(33) \times 10^{-6}$ | 20 |
| $^{6}Li(0^+,1) \to \alpha + d$ | 1 | $\Gamma_\alpha \leq 2.0 \times 10^{-6}$ eV (90% C.L.) | 22 |
| $^{16}O(2^-,0) \to \alpha + {}^{12}C$ | 0 | $\Gamma_\alpha = 1.03(28) \times 10^{-10}$ eV | 39 |
| $^{16}O(0^-,0) \to \alpha + {}^{12}C$ | 0 | $\Gamma_\alpha < 5 \times 10^{-4}$ eV (90% C.L.) | 40 |
| $^{16}O(3^+,0) \to \alpha + {}^{12}C$ | 0 | $\Gamma_\alpha < 8 \times 10^{-5}$ eV (90% C.L.) | 40 |
| $^{18}F(0^-,0) \to {}^{18}F + \gamma$ | 1 | $P_\gamma = -0.1(12) \times 10^{-3}$ | 29,30,31 |
| $^{19}F(1/2^-) \to {}^{19}F + \gamma$ | 0,1 | $A_\gamma = -8.5(26) \times 10^{-5}$ | 35 |
| $^{16}O + \alpha \to {}^{20}Ne$ (11.262) | 1 | $\Gamma_\alpha < 3.3 \times 10^{-5}$ eV (95% C.L.) | 41 |
| $^{19}F + p \to {}^{20}Ne$ (13.168) | 1 | $\Gamma_\alpha < 7 \times 10^{-6}$ eV | 42 |
| $^{19}F + p \to {}^{20}Ne$ (13.479) | 1 | $A_\alpha = 5.1(30) \times 10^{-3}$ | 30 |
| $^{21}Ne(1/2^-) \to {}^{21}Ne + \gamma$ | 0,1 | $P_\gamma = +2.3(29) \times 10^{-3}$ | 36 |
| $^{41}K(7/2^-) \to {}^{41}K + \gamma$ | 0,1,2 | $P_\gamma = 2.0(4) \times 10^{-5}$ | 1 |
| $^{113}Cd(n,\gamma)^{114}Cd$ | 0,1,2 | $A_\gamma = -3.4(7) \times 10^{-4}$ | 43 |
| | | $P_\gamma = -6.0(15) \times 10^{-4}$ | 43 |
| $^{117}Sn(n,\gamma)^{118}Sn$ | 0,1,2 | $A_\gamma = 6.3(20) \times 10^{-4}$ | 1 |
| $^{175}Lu(9/2^-) \to {}^{175}Lu + \gamma$ | 0,1,2 | $P_\gamma = 5.5(5) \times 10^{-5}$ | 1 |
| $^{180}Hf(8^-) \to {}^{180}Hf + \gamma$(.501) | 0,1,2 | $P_\gamma = -2.5(3) \times 10^{-3}$ | 1 |
| | | $A_\gamma = -0.017(2)$ | 1 |
| $^{181}Ta(5/2^+) \to {}^{181}Ta + \gamma$ | 0,1,2 | $P_\gamma = -5.2(5) \times 10^{-6}$ | 1 |

what the weak interaction, so an experimental determination is urgently needed. The most promising approach is perhaps a measurement of the pair internal conversion coefficient.

Of course, a "direct" measurement of a pure isovector case is highly desirable, and it is to be hoped that the four ΔT=1 experiments will be pushed still further, and that improved calculations will be made for the $^{6}$Li case. Nuclear parity violation seems to be rapidly approaching an interesting and useful synthesis.

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## REFERENCES

1. D. Tadic, Rep. Prog. Phys. 43:67 (1980).
2. J.M. Potter, J.D. Bowman, C.F. Hwang, J.L. McKibben, R.E. Mischke, D.E. Nagle, P.B. Debruhner, H. Frauenfelder, and L.B. Sorensen, Phys. Rev. Lett. 33:1307 (1974); D.E. Nagle, J.B. Bowman, C. Hoffman, J. McKibben, R. Mischke, J.M. Potter, H. Frauenfelder, and L. Sorensen, in "High Energy Physics with Polarized Beams and Polarized Targets" ed. G.H. Thomas, Am. Inst. Phys. New York (1978).
3. R. Balzer, R. Henneck, Ch. Jacquemart, J. Lang, M. Simonius, W. Haeberli, Ch. Weddigen, W. Reichart, and S. Jaccard, Phys. Rev. Lett. 44:699 (1980); M. Simonius, in "Fifth Int. Conf. on Polarization Phenomena" Santa Fe (1980).
4. N. Lockyer, T.A. Romanowski, J.D. Bowman, C.M. Hoffman, R.E. Mischke, D.E. Nagle, J.M. Potter, R.L. Talaga, E.C. Swallow, D. Alde, and D.R. Moffett, Bull. Am. Phys. Soc. 25:525 (1980).
5. C.M. Hoffman, private communication.
6. E.M. Henley and F.R. Krejs, Phys. Rev. D 11:605 (1975).
7. V.R. Brown, E.M. Henley and F.R. Krejs, Phys. Rev. C 9:935 (1974).
8. M. Simonius, Phys. Lett. 41B:415 (1972); M. Simonius, Nucl. Phys. A220:269 (1974).
9. G. Barton, Nuovo Cim. 19:512 (1961).
10. G.S. Danilov, Phys. Lett. 18:40 (1965).
11. V.M. Lobashov, D.M. Kaminker, G.I. Kharkevich, V.A. Kniazkov, N.A. Lozovoy, V.A. Nazarenko, L.F. Sayenko, L.M. Smotritsky, and A.I. Yegorov, Nucl. Phys. A197:241 (1972).
12. B.H.J. McKellar in "Int. Conf. on Frontiers of Physics", Singapore (1978).
13. A.B. McDonald, E.D. Earle and J.W. Knowles, contrib. to this conference.
14. H.C. Lee, Phys. Rev. Lett. 41:843 (1978).
15. C.Y. Prescott, et al., Phys. Lett. B77:347 (1978).
16. T.J. Bowles, private communication.
17. M. Gari in "Interaction Studies in Nuclei" ed. H. Jochim and B. Ziegler, North Holland, Amsterdam (1975).
18. K.R. Lassey and B.H.J. McKellar, Nucl. Phys. A260:413 (1976).

19. J.F. Cavaignac, B. Vignon and R. Wilson, Phys. Lett. 67B:148 (1977).
20. B. Vignon, private communication.
21. E. Bellotti, E. Fiorini, P. Negri, A. Pullia, L. Zanotti, and I. Filosofo, Nuovo Cim. 29A:106 (1975).
22. R.G.H. Robertson, R.A. Warner, P. Dyer, R.C. Melin, T.J. Bowles, A.B. McDonald, W.G. Davies, G.C. Ball and E.D. Earle, Progress Report, Michigan State University (1980) (unpublished).
23. F.C. Michel, Phys. Rev. 133:B329 (1964).
24. R.G.H. Robertson and D.O. Riska, unpublished.
25. J.D. Vergados, Nucl. Phys. A220:259 (1974).
26. P.G. Bizzetti and A. Perego, Phys. Lett. 64B:298 (1976).
27. C.A. Gagliardi, A.R. Davis, G.T. Garvey, R.D. McKeown, B. Myslek-Laurikainen, R.G.H. Robertson, S.J. Freedman, and T.J. Bowles, contrib. to "Fifth Int. Conf. on Polarization Phenomena" Santa Fe (1980).
28. W. Teeters and D. Kurath (unpublished).
29. C.A. Barnes, M.M. Lowry, J.M. Davidson, R.E. Marrs, F.B. Morinigo, B. Chang, E.G. Adelberger and H.E. Swanson, Phys. Rev. Lett. 40:840 (1978).
30. H. Waffler, private communication.
31. P.R. Maurenzig, M. Bini, P.G. Bizzetti, T.F. Fazzini, A. Perego, G. Poggi, P. Sona and N. Taccetti, in "Neutrinos 79", Bergen, p. 179 (1979); also P.R. Maurenzig, private communication.
32. B. Desplanques and J. Missimer, Nucl. Phys. A300:286 (1978).
33. B. Desplanques, J.F. Donoghue and B.R. Holstein, Ann. Phys. 124:449 (1980).
34. W.C. Haxton, B.F. Gibson and E.M. Henley, to be published.
35. E.G. Adelberger, H.E. Swanson, M.D. Cooper, J.W. Tape, and T.A. Trainor, Phys. Rev. Lett. 34:402 (1975); also E.G. Adelberger, private communication.
36. K.A. Snover, R. Von Lintig, E.G. Adelberger, H.E. Swanson, T.A. Trainor, A.B. McDonald, E.D. Earle, and C.A. Barnes, Phys. Rev. Lett. 41:145 (1978); also A.B. McDonald, private communication.
37. M. Forte, B. Heckel, N. Ramsey, K. Green, G. Greene, M. Pendlebury, W. Sumner, P.D. Miller and W. Dress, Bull. Am. Phys. Soc. 25:526 (1980).
38. See V.V. Flambaum and O.P. Sushkov, Phys. Lett. B (to be published).
39. K. Neubeck, H. Schober, and H. Waffler, Phys. Rev. C10:320 (1974).
40. E. Bellotti, E. Fiorini, C. Liquori, P. Negri, and L. Zanotti, in "Neutrinos-79" Bergen, p. 175 (1980).
41. L.K. Fifield, private communication.

42. N. Krimmelbein, H. Schober and H. Waffler, in "Int. Conf. on Nuclear Structure and Spectroscopy" Amsterdam, Vol. 1 p. 149 (1974).
43. Y.G. Abov and P.A. Krupchiskii, Sov. Phys. Usp. 19:75 (1976).
44. B.A. Brown, W.A. Richter and N.S. Godwin, to be published.
45. There is now some confusion over the sign of the $^{18}F$ result from Mainz. A sign change would allow a somewhat larger n.c. enhancement.