Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

TITLE: PARITY NONCONSERVATION IN LIGHT HADRONIC SYSTEMS

AUTHOR(S): Richard E. Mischke

LA-UR--84-2480

DEB4 016484

SUBMITTED TO: Particles and Nuclei X International Conference, Heidelberg,
July 29 - August 3, 1984.

DISCLAIMER

MASTER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

PARITY NONCONSERVATION IN LIGHT HADRONIC SYSTEMS

R. E. MISCHKE

Los Alamos National Laboratory, Los Alamos, New Mexico 87545

Parity-nonconservation experiments in light hadronic systems now provide a fairly consistent picture of the important weak coupling constants. One cause for concern is the ^{18}F system, which gives a limit that is becoming significantly small compared to the prediction. New results and some details of the experiments using 800 MeV polarized protons are given.

1. INTRODUCTION

The study of parity nonconservation in hadronic systems was first discussed in the context of parity conservation in the strong interactions.¹ Later the signal of parity nonconservation was recognized as a tool that could be used to study the weak interaction in the presence of an overwhelming strong force between hadrons. After several years of hard work, results were obtained for decays of several heavy nuclei that convincingly demonstrated parity nonconservation effects.² Generally, the early experiments were chosen to take advantage of nuclear structure effects that enhanced the interference between parity conserving and parity nonconserving amplitudes. Unfortunately because of the complicated nuclear structure these experiments are difficult to interpret. Most recent work has concentrated on nucleons and light nuclei. In this discussion, the experiments are divided into two categories. One class of experiments seeks to observe transitions that are forbidden by parity conservation or to observe a signal characteristic of an interference between parity-conserving and parity-nonconserving amplitudes. The other class of experiment uses a polarized proton beam to elicit a sensitivity to a pseudoscalar (parity nonconserving) scattering amplitude; these scattering experiments may involve a nuclear target.

To see the progression of experimental and theoretical results over the last few years, one might consult the proceedings from a relevant conference from each of the last five years: Bergen(1979),³ Santa Fe(1980),⁴ Lausanne(1981),⁵ Brookhaven(1982),⁶ Javea(1982),⁷ and Steamboat Springs(1984).⁸ The contributions in these volumes include excellent review articles and specific experimental results and calculations.

In Sec. 2, the results in nuclear systems are summarized. In Sec. 3 the experimental results in N-N and N-A scattering are discussed with an emphasis on the Los Alamos program. Some comments on the theoretical interpretation of the data are given in Sec. 4 and the contributions to this conference are mentioned in Sec. 5.

TABLE I. Parity nonconservation results in light nuclei.

Nucleus or Reaction	Quantity	Value	Reference
$np + d\gamma$	P_Y	$(1.8 \pm 1.8) \times 10^{-7}$	Knyaz'kov ⁹
$\bar{n}p + d\gamma$	A_Y	$(3 \pm 4) \times 10^{-8}$	Grenoble ¹²
$\bar{n}d + t\gamma$	A_Y	$(7.8 \pm 3.4) \times 10^{-6}$	Grenoble ¹³
${}^6\text{Li}(3.56 \text{ MeV})$	Γ_α	$< 6.5 \times 10^{-7} \text{ eV}$	Chalk River ¹⁴
${}^{16}\text{O}(8.88 \text{ MeV})$ (10.95 MeV) (11.08 MeV)	Γ_α	$(1.03 \pm 0.28) \times 10^{-10} \text{ eV}$ $< 8 \times 10^{-4} \text{ eV}$ $< 6.3 \times 10^{-5} \text{ eV}$	Mainz ¹⁵ Milan ¹⁶ Milan ¹⁶
${}^{18}\text{F}(4.753 \text{ MeV})$	Γ_α P_Y^α P_Y	$< 1.2 \times 10^{-5} \text{ eV}$ $(-0.7 \pm 2.0) \times 10^{-3}$ $(-0.4 \pm 3.0) \times 10^{-3}$ $(-1.0 \pm 1.8) \times 10^{-3}$ $(-0.23 \pm 0.86) \times 10^{-3}$	Bordeaux-Zaragoza ¹⁷ Caltech-Seattle ²⁰ Florence ²¹ Mainz ²² Queens ²³
${}^{19}\text{F}(110 \text{ keV})$	A_Y	$(-8.5 \pm 2.6) \times 10^{-5}$ $(-6.8 \pm 1.8) \times 10^{-5}$	Seattle ²⁴ Zürich ²⁵
${}^{20}\text{Ne}(11.26 \text{ MeV})$ (13.48 MeV)	Γ_α A_Z	$(4.2 \pm 2.0) \times 10^{-5}$ $< 6 \times 10^{-6}$ $(6.6 \pm 2.4) \times 10^{-3}$ $< 4 \times 10^{-3}$	Oxford ¹⁸ Giessen ¹⁹ Mainz ²⁸ Giessen ²⁹
${}^{21}\text{Ne}(2.789 \text{ MeV})$	P_Y	$(2.4 \pm 2.9) \times 10^{-3}$ $(0.7 \pm 1.6) \times 10^{-3}$	Seattle-Chalk River ²⁶ Chalk River-Seattle ²⁷

2. EXPERIMENTAL RESULTS IN NUCLEAR SYSTEMS

The present status of experiments in light nuclei is summarized in Table I. The first three experiments utilize thermal neutrons. The measurement⁹ of the circular polarization of the photon, P_Y , in $np + d\gamma$ resolves a long-standing problem with a previous result¹⁰ that was much larger than theoretical calculations.¹¹ The asymmetry of the photon, A_Y , from the capture of polarized

claim a discrepancy. Several experiments¹⁴⁻¹⁹ are listed that seek to observe a parity nonconserving decay width, Γ_a , of excited levels in ^6Li , ^{16}O , ^{18}F , and ^{20}Ne . The experiments²⁰⁻²⁷ measuring P_γ or A_γ in ^{18}F , ^{19}F , and ^{21}Ne have received the most attention in recent years because of the existence of low-lying parity mixed states with a small energy separation. Another experiment²⁸ has measured a surprisingly large value for A_z , the longitudinal asymmetry in ^{20}Ne . However, a contribution to this conference²⁹ obtains a result consistent with zero and with smaller errors.

This is an active area of research. As examples, there are plans to improve the result for the $\bar{n}p \rightarrow d\gamma$ experiment by a factor of five at Grenoble. There is a new experiment on ^{14}N at Seattle and there are continuing efforts on ^{18}F at Queens and Florence.

Another class of experiments that are relevant to this subject include the results from heavy nuclei and experiments with neutrons measuring the spin rotation or asymmetries in fission induced with polarized neutrons. Because of the difficulties with the nuclear structure parts of the calculations, these experiments will probably yield more information about nuclear dynamics than about the weak interaction. An excellent summary of the neutron experiments with heavy nuclei may be found in Ref. 30.

TABLE II. Parity nonconservation results in N-N and N-A scattering.

Reaction	Quantity	Value	Reference
p+p (15 MeV)	A_L	$(-1.7 \pm 0.8) \times 10^{-7}$	Los Alamos ³¹
(45 MeV)		$(-2.3 \pm 0.8) \times 10^{-7}$	SIN ³²
(45 MeV)		$(-1.3 \pm 2.3) \times 10^{-7}$	Berkeley ³³
(800 MeV)		$(1.0 \pm 1.6) \times 10^{-7}$	Los Alamos ³⁵
p+d (15 MeV)	A_L	$(-0.35 \pm 0.85) \times 10^{-7}$	Los Alamos ³¹
p+ α (45 MeV)	A_L	$(-3.3 \pm 0.6) \times 10^{-7}$	SIN ³⁴
p+H ₂ O (800 MeV)	A_L	$(1.7 \pm 3.3) \times 10^{-7}$	Los Alamos ³⁶
(6 GeV/c)		$(26.5 \pm 0.6) \times 10^{-7}$	ZGS ³⁷

3. EXPERIMENTAL RESULTS IN N-N AND N-A SCATTERING

The experiments described in this section all involve the use of a polarized

$A_L = (\sigma^+ - \sigma^-) / (\sigma^+ + \sigma^-)$ where σ^+ (σ^-) is the total cross section for scattering with incident helicity positive (negative).

Two geometries have been used. At high energies, a transmission geometry gives a direct measure of the total cross section, while at low energies the experiments tend to measure the scattered beam and integrate to obtain the total cross section. The results of these experiments are summarized in Table II.

The low energy pp experiments³¹⁻³³ are not new and are in good agreement with theoretical calculations. The pd result³¹ is also not new but the result³⁴ in pa replaces a previous value and now agrees with expectations. The experiments^{35,36} at 800 MeV provide data at an energy intermediate to previous experiments at low energies and the high energy experiment³⁷ on a water target at 6 GeV/c (5.3 GeV). Because the 6 GeV/c experiment observed an effect much larger than expected, it is important to test our ability to understand the energy dependence of the relevant physics.

The 800 MeV program of experiments has been under development for several years. A Lamb-shift type polarized source³⁸ produces a beam of longitudinally polarized protons whose helicity is reversed at 30 Hz. The position of the beam is stabilized by feedback systems. Ion chambers are used to measure the current of protons before and after the target. There are position and polarization detectors that monitor properties of the beam that might give rise to systematic effects. (See Fig. 1.) Several interesting technical problems have been encountered and solved along the way. I will mention some of these to illustrate problems that are common to this class of experiment.

The emphasis in any of these experiments is to identify and control systematic errors. For example, in an early version of the experiment we found that our measurement of the transmission was very noisy (more than fifteen times that expected from the contribution from proton statistics). Until we understood the origin of this noise, we could not be sure that it did not affect the experiment in a systematic way. It turned out that the problem was due to spallation products from the plates in the ion chambers and a redesign of the chambers cured the problem.³⁹ The present chambers have transverse plates (see Fig. 2) and are filled with hydrogen gas. This ensures that beam protons do not encounter any nuclei that could give rise to spallation products except in the end windows. The chamber design uses long snouts to remove the end windows far enough from the active volume that the spallation products are ranged out. However, just recently we discovered that the new ion chambers have a different and more subtle problem. Because they are operated with one

plate at ground and the other at high voltage, some electric field lines from the high voltage guard plate go to the can making a slight asymmetry. This causes a displacement of the neutral axis of the experiment (where corrections vanish) that depends on the distribution of scattered beam. As a consequence the axis through the ion chamber that corresponds to symmetry for beam position modulation is different from that determined for making the sensitivity to residual transverse polarization vanish.

The water result is based on 28 runs with a total of 18.0×10^{15} incident protons. Several corrections are applied to the raw result for contributions from 30 Hz modulations of the beam corresponding to intensity, position, and transverse polarization. Also a correction is made for the polarization distribution across the beam that reverses at 30 Hz. These corrections change the central value of the result by about 1σ . The final result for the water target is given in Table II.

The analysis of the hydrogen data has not been completed but a preliminary result is given for p-p in Table II. Data have just been taken on a liquid deuterium target with a statistical precision of $A_L \sim 1 \times 10^{-7}$.

4. THEORETICAL STATUS

Traditionally, the picture of the interaction between hadrons is via meson exchange. In describing the interaction at low energies, only S and P waves are important. This means that the exchange of light mesons will dominate in importance with one vertex described by the strong interaction and the other by the weak interaction. It is necessary to obtain the weak meson-nucleon coupling and this has been done by Desplanques, Donoghue, and Holstein⁴⁰ using known nonleptonic hyperon decays. Because the hyperon decays are strangeness-changing, the couplings are related to the ones needed here by SU(6) rotations.

Recently a successful theory of the weak interactions has emerged.⁴¹ Now it is possible to describe the weak interactions between quarks directly. It is of considerable interest to relate this picture of the weak interaction to that used before and to determine the effect of the hadronic environment. We may have a fundamental theory of the weak interaction, but there are still mysteries. For example, the $\Delta I = 1/2$ rule is not understood.

Because direct W and Z exchange between nucleons is not plausible at low energies, the meson exchange picture is still used.^{42,43} The expected exchanges include π , ρ , and ω . These can be further classified according to their

is dominated by the $\Delta I = 0, 2$ piece. The charged current $\Delta I = 1, \Delta S = 0$ piece is Cabibbo suppressed by a $\sin^2 \theta_C$ factor of ~ 0.05 . A recent development⁴⁴ is a hybrid model that seeks to combine a quark picture for the short-range parts of the interaction while retaining π exchange for the long-range part.

At low energies, there are five allowed transitions between S and P wave states in nuclei. These include all isospin combinations and must be determined by at least five independent experiments. Because several amplitudes are involved, several experiments are required. A fairly good picture can be obtained from the results in p-p scattering, p- α scattering, and γ circular polarization in ^{18}F and ^{19}F . To obtain the couplings from the nuclear experiments, it is necessary to handle the nuclear structure effects. In the case of ^{18}F and ^{19}F it has been possible⁴⁵ to circumvent most of the uncertainties by studying beta decays of ^{18}Ne and ^{19}Ne . A very illuminating result of this work has been the discovery that the couplings need to be reduced by a factor of three from the predictions of shell model calculations.

In ^{18}F , ^{19}F , and ^{21}Ne the parity mixtures are well described by the "two-state mixing" approximation. For example, in ^{18}F the $0^-, I = 0$ state at 1081 keV decays to the $1^+, I = 0$ ground state by an E1 transition. The $0^+, I = 1$ state at 1042 keV decays to the ground state by an allowed M1. The PNC mixing of these states leads to a P_γ .

These experiments are very difficult and progress has come slowly, but now there is sufficient information of adequate quality to permit a measurement of the Weinberg angle from these data⁴⁶. An analysis of neutral currents gives $\rho = 1.1 \pm 0.2$ and $\sin^2 \theta_W = 0.0 \pm 0.4$.

Holstein has used the p-p and p- α data to determine $f_\pi = (13 \pm 6) \times 10^{-7}$ and $h_\rho^0 = (-25 \pm ?) \times 10^{-7}$. He has also analyzed the data from the sd shell from ^{18}F and ^{21}Ne to obtain $f_\pi = (10 \pm 2) \times 10^{-7}$ and $h_\rho^0 = (27 \pm 6) \times 10^{-7}$. He concludes that the meson-exchange picture gives consistent results. The prediction for ^{18}F is 13×10^{-4} . Haeblerli has used the data from p- α scattering, ^{19}F , and ^{21}Ne to obtain the values $f_\pi = (4.4 \pm 0.9) \times 10^{-7}$ and $h_\rho^0 + 0.54 h_\omega^0 = (-11 \pm 2) \times 10^{-7}$. The present result in ^{18}F restricts $f_{\pi p}$ to be $< 5 \times 10^{-7}$. It is crucial to receive the results of improved experiments in ^{18}F to see if there is really a problem.

The result at 6 GeV/c in p- H_2O scattering reminded us of the limitations of the meson exchange picture. Here meson exchange calculations⁴⁷ cannot predict the experimental result. However, a calculation at the quark level⁴⁸ is able to reproduce the experimental result. In addition there is another approach

that considers the effects of wave-function renormalization,⁴⁹ but this calculation is controversial.⁵⁰⁻⁵²

5. CONTRIBUTIONS TO THIS CONFERENCE

There is a contribution to this conference from K. E sener et al. that discusses the implication of their recent result²⁵ on f_π and h_ρ . B. Desplanques and S. Noguera conclude that parity violation in the nucleon wave function⁴⁹ is cancelled by other diagrams that restore current conservation. J. Lang et al. report their new result³⁴ for p- α scattering. N. Kniest et al. describe a new experiment on isovector parity mixing in ^{20}Ne . The result²⁹ for A_z does not agree with a previous measurement.²⁸ The paper by V. Kopeliovich proposes a study of parity nonconservation in $NN \rightarrow NN\gamma$ with effects expected at the 10^{-6} level. V.V. Burov et al. give their published result⁵³ that Γ_α for $^6\text{Li}(3.56 \text{ MeV})$ is $\sim 10^{-11}$. Finally, V. Ravishanker et al. calculate the effect of parity violation in $\gamma d \rightarrow \pi^0 d$ as a probe of p-state components in the deuteron.

6. CONCLUSION

Many years of experimental and theoretical effort have left us with a fairly consistent picture of the weak interaction between hadrons. While the original emphasis of the program was to learn about the weak interaction, using known strong interaction amplitudes, the tables have turned. It is ironic that now we are more hampered by our lack of understanding of the strong interaction and may be able to use these experiments to learn more about the validity of the meson exchange picture and as a testing ground for some aspects of QCD. This is not to say that all is understood about the weak interaction. There are still mysteries and discrepancies. Even though the experimental techniques are impressive, it will be necessary to make continued improvements if the results are going to impact our candidate theories of the fundamental interactions.

ACKNOWLEDGEMENT

The results presented here represent the work of many individuals over a period of more than a decade. I would like to thank all my colleagues involved in the Los Alamos work as well as others from around the world whose efforts appear in this report.

REFERENCES

- 1) D.H. Wilkinson, Phys. Rev. 109 (1958) 1603.
- 2) See the review by F. Boehm, High-Energy Physics and Nuclear Structure-1975, Santa Fe, eds. D.E. Nagle et al., AIP Conference Proceedings No. 26 (American Institute of Physics, New York, 1975).
- 3) Proceedings of Neutrino 79, Bergen, eds. A. Haatuft and C. Jarlskog (Astvedt Industrier, Bergen, 1979).
- 4) Polarization Phenomena in Nuclear Physics-1980, Santa Fe, eds. G. G. Ohlsen et al., AIP Conference Proceedings No. 69 (American Institute of Physics, New York, 1981).
- 5) High Energy Physics with Polarized Beams and Polarized Targets, Lausanne, eds. C. Joseph and J. Soffer, Experientia Supplementum No. 38 (Birkhäuser Verlag, Basel, 1981).
- 6) High Energy Spin Physics-1982, Brookhaven, ed. G. M. Bunce, AIP Conference Proceedings No. 95 (American Institute of Physics, New York, 1983).
- 7) Weak Interactions and Neutrinos, Javea, ed. A. Morales, (World Scientific, Singapore, 1983).
- 8) Conference on the Intersections between Particle and Nuclear Physics, Steamboat Springs, ed. R.E. Mischke, AIP Conference Proceedings (to be published).
- 9) V.A. Knyaz'kov et al., Nucl. Phys. A417 (1984) 209.
- 10) V.M. Lobashov et al., Nucl. Phys. A197 (1972) 241.
- 11) G.S. Danilov, Phys. Lett. B35 (1971) 597; Sov. J. Nucl. Phys. 14 (1971) 788; V.B. Kopeliovich, Sov. J. Nucl. Phys. 35 (1982) 716.
- 12) R. Wilson, private comm.
- 13) M. Avenier et al., Phys. Lett. 137B (1984) 125.
- 14) R.G.H. Robertson et al., Phys. Rev. C 29 (1984) 755.
- 15) K. Neubeck et al., Phys. Rev. C 10 (1974) 320.
- 16) E. Bellotti et al., ref. 3, vol. 2, p. 175.
- 17) F. Leccia et al., ref. 7, p. 595.
- 18) L.K. Fifield et al., Nucl. Phys. A394 (1983) 1.
- 19) N. Kniest et al., Phys. Rev. C 27 (1983) 906.
- 20) C.A. Barnes et al., Phys. Rev. Lett. 40 (1978) 840.
- 21) P.G. Bizzeti et al., Lett. Nuovo Cim. 29 (1980) 167.
- 22) G. Ahrens et al., Nucl. Phys. A390 (1982) 486.
- 23) A.B. McDonald, Bull. Am. Phys. Soc. 29 (1984) 666.
- 24) E.G. Adelberger et al., (to be published).
- 25) K. Elsener et al., Phys. Lett. 117B (1982) 167; Phys. Rev. Lett. 52 (1984) 1476.
- 26) K.A. Snover et al., Phys. Rev. Lett. 41 (1978) 145; E. Adelberger, in ref. 4, p. 1367.
- 27) E.D. Earle et al., Nucl. Phys. A396 (1983) 221.
- 28) J. Ohlert, O. Traudt, and H. Wäffler, Phys. Rev. Lett. 47 (1981) 475.
- 29) N. Kniest et al., (this conference).
- 30) B. Desplanques, in ref. 7, p. 515.
- 31) D.E. Nagle et al., in High Energy Physics with Polarized Beams and Targets, ed. G.H. Thomas, AIP Conference Proceedings No. 51, (American Institute of Physics, New York, 1978), p. 224.
- 32) R. Balzer et al., Phys. Rev. Lett. 44, 699 (1980); W. Haeberli, in ref. 4, p. 1340; M. Simonius, in ref. 5, p. 355.
- 33) P. von Rossen, U. von Rossen, and H.E. Conzett, in ref. 4, p. 1442.
- 34) R. Henneck et al., Phys. Rev. Lett. 48 (1982) 725; W. Haeberli, in ref. 8.

- 35) R.E. Mischke et al., submitted to the XXII International Conference on High Energy Physics, Leipzig (1984).
- 36) D.E. Nagle, in ref. 6, p. 150; R. Harper et al., to be published.
- 37) N. Lockyer et al., Phys. Rev. Lett. 45, 1821 (1980); Phys. Rev. (to be published).
- 38) J. McKibben, in ref. 4, p. 830.
- 39) J.D. Bowman et al., Nucl. Instrum. Methods. 216 (1983) 399.
- 40) B. Desplanques, J. F. Donoghue, and B. R. Holstein, Ann. Phys. 124 (1980) 449.
- 41) S. Weinberg, Phys. Rev. Lett. 19 (1967) 1264; A. Salam, in Elementary Particle theory: Relativistic Groups and Analyticity, Proc. 8th Nobel Symp., ed. N. Svartholm (Almqvist and Wiksell, Stockholm, 1968), p. 367; S.L. Glashow, J. Iliopoulos, L. Maiani, Phys. Rev. D 2 (1970) 1285.
- 42) V. R. Brown, E. M. Henley, and F. R. Kres, Phys. Rev. C 9, 935 (1974).
- 43) M. Simonius, Nucl. Phys. A220, 269 (1974)
- 44) L. S. Kisslinger and G. A. Miller, Phys. Rev. C 27, 1602 (1983).
- 45) E.G. Adelberger et al., Phys. Rev. C 27 (1983) 2833.
- 46) B. Holstein, in ref. 8.
- 47) E. M. Henley and F. R. Kres, Phys. Rev. D 11, 605 (1975).
- 48) T. Goldman and D. Preston, Nucl. Phys. B217, 61 (1983).
- 49) G. Nardulli and G. Preparata, Phys. Lett. 117B, 445 (1982).
- 50) J.F. Donoghue and E.R. Holstein, Phys. Lett. 125B, 509 (1983).
- 51) G. Nardulli and G. Preparata, Phys. Lett. 137B (1984) 111.
- 52) B.H.J. McKellar, Phys. Lett. 138B (1984) 6.
- 53) V.V. Burov et al., J. Phys. G 10 (1984) L21.

FIGURE 1

Schematic for the H₂O experiment.

FIGURE 2
Ion chamber used in the 800 MeV scattering experiments.