If the experiment is not symmetric in $\cos\theta$, additional correlations of the form $\sin\theta\cos\theta\cos\varphi$ will be present (and could be calculated).

This work was supported in part through funds provided by the U. S. Department of Energy under Contract No. EY-76-C-02-3069. One of us (R.L.J.) acknowledges receipt of an A. P. Sloan Foundation Fellowship.

---

[1] S. D. Drell, D. Levy, and T.-M. Yan, Phys. Rev. 187, 2159 (1959), and Phys. Rev. D 1, 1617 (1970); R. P. Feynman, *Photon-Hadron Interactions* (Benjamin, Reading, Mass., 1972).

[2] G. Sterman and S. Weinberg, Phys. Rev. Lett. 39, 1436 (1977).

[3] E. Farhi, Phys. Rev. Lett. 39, 1587 (1977); H. Georgi and M. Machacek, Phys. Rev. Lett. 39, 1237 (1977); S. S. Shei, to be published.

[4] A. De Rújula, J. Ellis, E. G. Floratos, and M. K. Gaillard, CERN Report No. Ref. TH. 2455, 1978 (to be published).

[5] Our argument assumes the QED vertex precedes the QCD vertex. In the opposite time ordering a $\cos\varphi$ dependence can arise but this vanishes when integrated over the remaining final-state phase space.

Upper Limit on Parity Mixing in ^{21}Ne

K. A. Snover, R. von Lintig, E.G. Adelberger, H. E. Swanson, and T. A. Trainor
Physics Department, University of Washington, Seattle, Washington 98195

and

A. B. McDonald and E. D. Earle
Atomic Energy of Canada Limited, Chalk River Nuclear Laboratories, Chalk River, Ontario K0J 1J0, Canada

and

C. A. Barnes
California Institute of Technology, Pasadena, California 91125
(Received 12 May 1978)

The parity-nonconserving circular polarization of γ rays from the 2.789 → 0.0 MeV transition in ^{21}Ne is found to be $(-9 \pm 51) \times 10^{-4}$, which corresponds to a parity-mixing matrix element $|\langle H_{\mathrm{PNC}}\rangle| = 0.009 \pm 0.054$ eV between the 2.80-MeV, $J^\pi = \frac{1}{2}^\pm$ levels. This value is considerably smaller than the measured parity mixing in the $J = \frac{1}{2}$ doublet in ^{19}F.

As yet we know very little about the parity-nonconserving (PNC) interaction between two nucleons. In particular the relative strengths of the $\Delta T = 0$, 1, and 2 components of the PNC interaction, which provide information on the basic hadronic weak interaction,[1] are not yet determined. These isospin properties are best found from experiments in light nuclei. However, nonzero effects have been seen only in three cases: $n + p$,[2] ^{16}O,[3] and ^{19}F.[4] These are not sufficient to determine the effective PNC N-N potential, even if one includes the precise upper limits obtained for $p + p$, $p + d$,[5] ^{18}F,[6] and the many circular polarization (P_γ) results in heavy nuclei.[7]

A particularly interesting system for studying nuclear parity mixing occurs at $E_x = 2.8$ MeV in ^{21}Ne where a $J^\pi = \frac{1}{2}^+$ and a $J^\pi = \frac{1}{2}^-$ level are separated by only 7.6 ± 0.7 keV (see Millener *et al.*[8]). We have chosen to examine this system for two reasons which we discuss more fully below: First, our measurement in ^{21}Ne is the first in an odd-N, even-Z nucleus, where the PNC matrix element connecting two levels of opposite parity can be inferred directly from a measurement of the pseudoscalar observable; and second, the ^{21}Ne system is unusually sensitive—a very small PNC matrix element produces relatively large experimental effects.

All measurements which show definite PNC effects in nuclei with odd $A = N + Z$ have been in odd-Z nuclei. In the single-particle approximation the PNC effects in all these odd-Z nuclei measure nearly the same linear combination of the basic PNC N-N amplitudes. By studying an odd-N nucleus one probes a different linear combination. For example, consider a schematic model where the $J^\pi = \frac{1}{2}^-$ level in ^{19}F (odd Z) consists of a proton hole in the $T = 0$ ^{20}Ne core while the $\frac{1}{2}^-$ level in ^{21}Ne (odd N) consists mainly of a nucleon hole in the $A = 22$, $T = 1$ core. From sim-

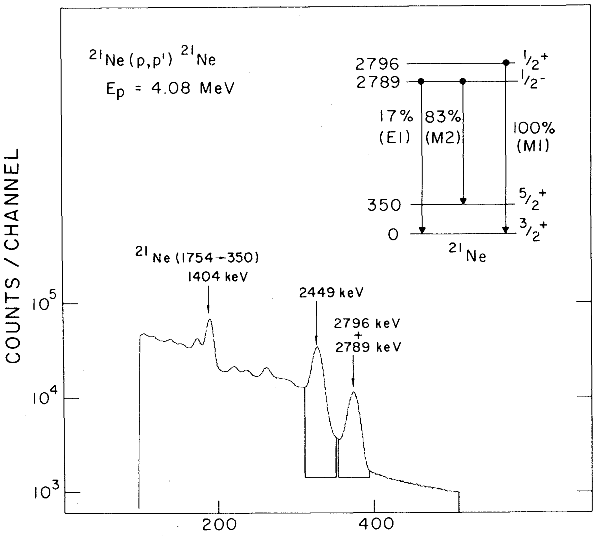

FIG. 1. Pulse-height spectrum from a NaI detector in the γ-ray polarimeter. Inset shows a partial level diagram for ^{21}Ne.

ple isospin considerations the ratio of isovector to isoscalar PNC mixing in ^{21}Ne will be $-\frac{1}{3}$ that of ^{19}F. A realistic calculation[8] gives $-1/1.7$ for this ratio.

It is easy to understand the great sensitivity of the ^{21}Ne system. The parity impurities in the 2.789-MeV $\frac{1}{2}^-$ and 2.796-MeV $\frac{1}{2}^+$ levels (see Fig. 1) are well approximated by simple two-level mixing:

$$|2.789\rangle = |-\rangle + \epsilon|+\rangle,$$
$$|2.796\rangle = |+\rangle - \epsilon|-\rangle,$$
$$\epsilon = \langle +|H^{\mathrm{PNC}}|-\rangle/\Delta E.$$

The resulting circular polarization P_γ of the γ rays de-exciting the two states is (to first order in the mixing ratio) $P_\gamma(2.789) = +2\epsilon\langle M1\rangle/\langle E1\rangle$ and $P_\gamma(2.796) = -2\epsilon\langle E1\rangle/\langle M1\rangle$. The dipole matrix elements $\langle M1\rangle$ and $\langle E1\rangle$ can be deduced[9] from the known lifetimes and branching ratios (we assume that the 2.789-MeV γ ray is predominantly $E1$). The $E1$ decay 2.789 → 0.0 is highly retarded [$\tau_{\gamma 0} = \tau/R = 696 \pm 51$ ps (see Ref. 8)] while the $M1$ decay 2.796 → 0.0 is fast ($\tau_{\gamma 0} = 5.3$ fs).[10] This leads to a negligible $P_\gamma(2.796)$ and a large expected value for $P_\gamma(2.789)$:

$$|P_\gamma(2.789)| = |(9.5\times10^{-2}\ \mathrm{eV}^{-1})\langle +|H^{\mathrm{PNC}}|-\rangle|.$$

For similar reasons the 2.4-MeV γ ray from the 2.789 → 0.350 MeV transition is expected to have a small P_γ. The sensitivity in ^{21}Ne can be illustrated by assuming that $\langle +|H^{\mathrm{PNC}}|-\rangle$ is comparable to the value obtained in Ref. 4 for ^{19}F (0.9 eV). This leads to $|P_\gamma(2.789)| = 8.6\times10^{-2}$ for ^{21}Ne compared to the asymmetry $A_\gamma = -(18\pm9)\times10^{-5}$ observed[4] in ^{19}F.

Our experiment detects the parity mixing by measuring $P_\gamma(2.789)$. We simultaneously measure $P_\gamma(2.4)$ which serves as a convenient check on our techniques since it should give a null result. The 2.789-MeV, $\frac{1}{2}^-$ level of ^{21}Ne was populated by the reaction ^{21}Ne(p,p') at $E_p = 4.08$ MeV, near the peak of a 30-keV-wide resonance in the yield of γ's from this level. In measurements made by McDonald, Earle, and Love[11] this reaction was found to be significantly more favorable than either the reaction ^{18}O(α,n) (Switkowski *et al.*[12]) ^{20}Ne(d,p). The 4.8-mm-long gas target contained 1.25 atm of ^{21}Ne gas (94.5% enriched) between a 2.5-mg/cm^2 molybdenum foil and a water-cooled platinum beam stop. A 7-μA proton beam from the University of Washington's model *FN* tandem Van de Graaff was diffused over a 2-mm-diam spot by passing it through a 50-μg/cm^2 carbon foil 2 m before the target. The circular polarization was analyzed in two transmission-type γ-ray polarimeters developed for a previous measurement in ^{18}F.[6] The lead shielding was modified slightly to accommodate two magnetically shielded and gain-stabilized 7.5-cm × 7.5-cm NaI(Tl) detectors. The polarimeters were carefully designed so that γ rays from the target, other than those passing through the Fe core, were strongly attenuated by heavy-metal shielding ($\rho = 17$ g/cm^3). The analyzing power (η) of the polarimeters was previously measured[6] from γ's from a ^{60}Co source. An extrapolation to 2.8 MeV using known Compton cross sections yields a value of $\eta = (3.41 \pm 0.10)\times10^{-2}$. The magnetizations of the two polarimeters were always parallel and reversed every two seconds. The magnetic fields in the polarimeters were monitored continuously by sense coils wound around the polarimeter cores. Pulse-height spectra from the two NaI detectors were recorded in separate multichannel analyzers with the spectra for the two senses of polarimeter magnetization routed into different memory regions. Data collection was halted for a period of 150 msec beginning 1 msec before each change of magnetization. Every 15 min the accumulated spectra were transferred to a computer for online analysis and written on magnetic tape, and the analyzer memories were cleared. Twice each day the current connections to the polarimeter coils were reversed, so that the sense of polar-

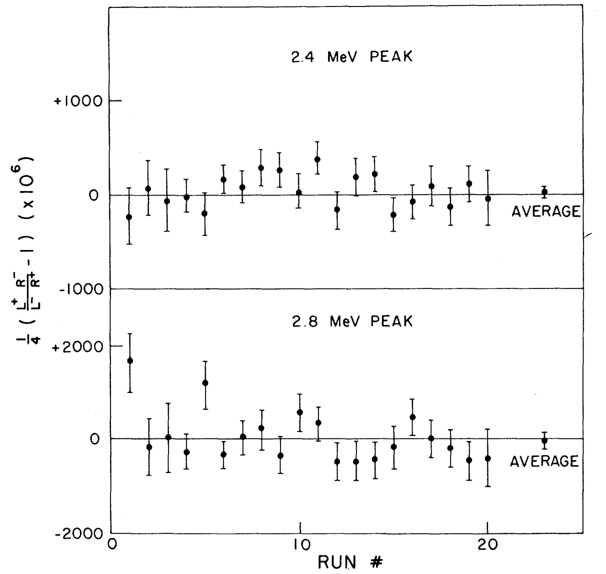

FIG. 2. Values of the asymmetry A obtained for runs of about 12 h duration.

ization was inverted relative to the remainder of the electronic circuitry. Data were accumulated for a total integrated charge of 5.0 C.

A typical γ-ray spectrum is shown in Fig. 1. The photopeak at 2.8 MeV from the unresolved $\frac{1}{2}^- \to \frac{3}{2}^+$ and $\frac{1}{2}^+ \to \frac{3}{2}^+$ transitions is clearly resolved from the peak at 2.4 MeV from the $\frac{1}{2}^- \to \frac{5}{2}^+$ transition. The small, slowly varying background is due to high-energy neutron-capture γ rays. For the 2.8- and 2.4-MeV photopeak regions indicated on the figure, asymmetries

$$A = \tfrac{1}{4}[(R_-L_+/R_+L_-) - 1]$$

were calculated, where R_-, R_+, L_-, and L_+ denote the excess counts above the smooth background for the right and left detectors in the two magneitzation states. Very small gain difference ($\leq 0.05\%$) were observed in the spectra for the two magnetization states. Therefore, the centroids of the 2.4- and 1.4-MeV peaks [^{21}Ne(1.754) $\to$ ^{21}Ne(0.350)] were used to determine an energy calibration for each spectrum from which identical energy windows were selected for the determination of R_+, R_-, etc.

Asymmetries for the 2.4- and 2.8-MeV peaks (Fig. 2) and for a background region above the 2.8-MeV peak were measured to be $A = (24 \pm 44) \times 10^{-6}$, $A = (-17 \pm 90) \times 10^{-6}$, and $(-87 \pm 127) \times 10^{-6}$, respectively, with reduced χ^2's of 0.9, 1.3, and 0.8. The null result for the 2.4-MeV peak demonstrates that any systematic errors are significantly smaller than the quoted uncertainty in $P_\gamma(2.796)$. The asymmetry of the 2.8-MeV photopeak, A, is related to $P_\gamma(2.789)$ by $P_\gamma(2.789) = A/f\eta$, where f ($=0.52$) is the fraction of the photopeak due to the $\frac{1}{2}^- \to \frac{3}{2}^+$ transition determined from the yield of 2.4-MeV γ rays and the known branching ratio. We obtain a circular polarization

$$P_\gamma(2.789) = (-9 \pm 51) \times 10^{-4}.$$

This corresponds to a parity-nonconserving matrix element $|\langle H_{\mathrm{PNC}}\rangle| = 0.009 \pm 0.054$ eV between the 2.80 $J = \frac{1}{2}$ levels, which is considerably smaller than the measured parity mixing[4] in the ^{19}F $J = \frac{1}{2}$ doublet.

In contrast to ^{19}F and ^{18}F, no theoretical calculations of parity mixing in ^{21}Ne have been published. However, Millener[13] has made a preliminary prediction of $\langle |H_{\mathrm{PNC}}| \rangle = 0.13$ eV using shell-model wave functions with an SU(3) basis and an effective one-body PNC potential. Brandenburg, McKellar, and Morrison[14] have used two-body PNC matrix elements determined for ρ and π exchange in the factorization approximation with various shell-model wave functions to calculate Cabibbo-model PNC matrix elements ranging from 0.02 to 0.19 eV. In all of these calculations, a strong ($f_\pi/f_{\pi_c} \gtrsim 10$) neutral-current enhancement would lead to values of $\langle H_{\mathrm{PNC}} \rangle$ at least a factor of 2 bigger than our present upper limit. Calculations using a two-body potential in a more complete shell-model basis are in progress.[13,14]

Experimental results now exist for two-level parity mixing in ^{18}F, ^{19}F, and ^{21}Ne, which involve different combinations of the $\Delta T = 0$ and $\Delta T = 1$ PNC N-N interaction. Once the nuclear structure theory in ^{21}Ne is reliable, the experimental and theoretical results can be combined to yield the isoscalar and isovector components of the PNC N-N interaction. It should then be possible to detemine whether or not $\Delta T = 1$ PNC transitions are enhanced by neutral weak currents as has been predicted by calculations[1] based on the Weinberg-Salam model.

We thank B. H. J. McKellar for suggesting this experiment and both McKellar and D. J. Millener for sending their results to us before publication. This work was supported in part by the U. S. Department of Energy and the National Science Foundation.

---

[1] M. Gari and J. H. Reid, Phys. Lett. 53B, 237 (1974);

B. Desplanques and J. Micheli, Phys. Lett. 68B, 339 (1977); J. Donoghue, Phys. Rev. D 13, 2064 (1976), and 15, 184 (1977).

[2] V. M. Lobashov *et al.*, Nucl. Phys. A197, 241 (1972).

[3] K. Neubeck *et al.*, Phys. Rev. C 10, 320 (1974).

[4] E. G. Adelberger *et al.*, Phys. Rev. Lett. 34, 402 (1975).

[5] J. M. Potter *et al.*, in Proceedings of the Symposium on Polarized Beams and Targets, Argonne National Laboratory, 1976 (unpublished).

[6] C. A. Barnes *et al.*, Phys. Rev. Lett. 40, 840 (1978).

[7] M. Gari, Phys. Rev. C 6, 319 (1973).

[8] D. J. Millener, E. K. Warburton, K. A. Snover, P. G. Ikossi, and R. Von Lintig, to be published.

[9] There is at present a sign ambiguity in $\langle E1 \rangle$ since the lifetime determines only $\langle E1 \rangle^2$ and the theoretical sign is not believed to be reliable. Until this is resolved one can only infer the magnitude of $\langle H_{\mathrm{PNC}} \rangle$ from a measurement of P_γ.

[10] Calculated by Millener (Ref. 8). This is consistent with two experimental results—H. Grawe *et al.*, Z. Phys. A280, 271 (1977), and E. K. Warburton, J. W. Olness, and C. J. Lister, private communication.

[11] A. B. McDonald, E. D. Earle, and M. A. Lone, Bull. Am. Phys. Soc. 23, 520 (1978).

[12] Z. E. Switkowski *et al.*, Phys. Rev. C 16, 1264 (1977).

[13] D. J. Millener, private communication.

[14] R. A. Brandenburg, B. H. J. McKellar, and I. Morrison, to be published; B. H. J. McKellar, private communication.

Analyzing Power in Inclusive Proton-Nucleus Cross Sections

S. Frankel, W. Frati, and M. Gazzaly
Physics Department, University of Pennsylvania, Philadelphia, Pennsylvania 19104

and

G. W. Hoffmann
Physics Department, University of Texas at Austin and Los Alamos Scientific Laboratory, Los Alamos, New Mexico 87545

and

O. Van Dyck
Los Alamos Scientific Laboratory, Los Alamos, New Mexico 87545

and

R. M. Woloshyn
TRIUMF, Vancouver, British Columbia, Canada, and University of British Columbia, Vancouver, British Columbia V6T1W5, Canada

(Received 3 October 1977; revised manuscript received 9 June 1978)

This paper reports measurements of the analyzing power, A_y, in the production of both "backward" protons and forward (quasifree scattering) protons in the reaction $p+A \rightarrow p+X$, using 800-MeV polarized protons. For the backward protons the measurements show large negative A-dependent values of A_y at low momenta, changing to large positive values at high momenta; in the quasielastic region, A_y is large and positive, is smaller than A_y measured in hydrogen, and decreases with increasing A.

The measurement of inclusive cross sections in the reaction $p+A \rightarrow p+X$, in kinematic regions forbidden in p-p reactions on free stationary protons, provides data that are sensitive to the high-momentum components in nuclei. Some of the general aspects of such studies appear in the recent literature[1-7] and several models[1,3,8-10] have been offered that attempt to account for the backward and, in particular, 180° production of high-momentum protons[11] and that differ greatly both in their assumed mechanisms and in their physical models of the nucleus.

Frankel and Woloshyn[12] (FW have recently pointed out how measurements of the analyzing power,[13] A_y, for the reaction $p_{\mathrm{polarized}}+A \rightarrow p+X$ are sensitive to and can distinguish between such models of high-momentum behavior within nuclei. For example, in the single-scattering model[1,2] shown in Fig. 1(a) the incoming proton of momentum $\vec{p}$ lifts a target nucleon of virtual momentum $\vec{k}$ on to the mass shell with observed momentum $\vec{q}$. FW *estimate* the analyzing power from the measured analyzing power[14] for p-p interactions using the values of s and t appropriate to interactions with a bound nucleon of momentum $\vec{k}$. For backwardly detected protons