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Isovector parity mixing in ^{20}Ne

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The parity- and isospin-forbidden α_0 decay from $^{20}Ne^*$ ($J^\pi=1^+$; $T=1$; $E_x=13.482$ MeV) to ^{16}O(g.s.) has been investigated by measurement of the longitudinal analyzing power A_z of the reaction $^{19}F(\vec{p},\alpha_0)^{16}O$ around the 1^+ resonance in $^{20}Ne^*$. With the data, the range for the expected interference effect has been reduced to $A_z=(15.0\pm7.6)\times10^{-4}$ (68% c.l.), significantly smaller than a previous result. An analysis for the new data and those of related experiments has been performed to extract upper limits for the irregular α_0 width $\Gamma_{\alpha_0}^{\mathrm{PNC}}$ and the weak pion nucleon coupling constant f_π, being smaller than previous theoretical expectations.

Isovector parity nonconservation (PNC) is of special interest for the study of the parity-violating weak nucleon-nucleon force, since it is particularly sensitive to the presence of neutral weak currents, which are expected to produce an enhancement in the weak pion nucleon coupling constant f_π.[1] However, the observation of the pure isovector part of the PNC potential between nucleons is limited to a small number of reported experiments ($\vec{n}+p$, ^{6}Li, ^{18}F, ^{20}Ne) from which the only stringent upper limit within the theoretically expected Desplanques-Donoghue-Holstein (DDH) interval[1] presently comes from the ^{18}F experiments ($f_\pi\leq1.2\times10^{-7}$).[2] This result strongly limits the theoretically expected range for f_π and is in contrast to the analyzed f_π- values from those experiments which have to be described by more than one isospin component of the weak nucleon-nucleon (NN) potential (i.e., $\vec{p}+\alpha$, ^{19}F, ^{21}Ne). Therefore, independent experiments involving other light nuclei may help to clarify the present inconsistencies.

A favorable case to study isovector parity mixing in the $J^\pi=1^+$, $T=1$ level in $^{20}Ne^*$ ($E_x=13.482$ MeV, $\Gamma=6$ keV) had been proposed first by Gari,[3] who calculated α_0-decay widths for the Cabibbo and Weinberg-Salam model of weak hadronic interactions.

The parity- and isospin-forbidden α_0 decay to ^{16}O(g.s.) can be investigated by measurement and analysis of the PNC transverse and longitudinal analyzing powers of the $^{19}F(\vec{p},\alpha_0)^{16}O$ reaction,[4] both requiring the quantization axis to be coplanar with the reaction plane. Similarly, as in our previously reported experiment with transversally polarized protons,[5] the narrow 1^+,1 state in ^{20}Ne was populated by resonant capture of longitudinally polarized protons ($E_p\approx670$ keV) from the Giessen polarization facility. As this level can only decay to ^{16}O(g.s.) via an admixture of negative parity, an interference effect of the order $4\times10^{-3}-3\times10^{-2}$ is expected[3,4] between the PNC transition amplitude and parity allowed transition amplitudes from overlapping resonance levels.

The longitudinal PNC asymmetry has been measured at eight energies around the 1^+ resonance energy using a setup of two detector rings, each equipped with four surface barrier detectors (300 mm^2) at $\theta_{\mathrm{Lab}}=90°$ ($\phi=0°$, 90°, 180°, 270°) covered with 10 μm Al foils to stop elastically scattered protons and low energy α particles from excited ^{16}O levels. Because of the small resonance width thin C-^{7}LiF-C solid targets with a thickness of $\sqrt{2}$(10-35-10) nm have been used, mounted with an angle of 45° with respect to the beam direction in the geometrical center of each detector ring, shown in Fig. 1.

The pulses of the α particles of each detector have been amplified by standard electronics and transferred to the memory of a *pdp* 11/10 computer using a 5 MHz multiplexer.

A careful control and correction of instrumental asymmetries has been applied to each spectrum. This has been achieved by on-line monitoring residual transverse polarization components from the detectors in the left-right and up-down position. Beam displacement on each target has been calculated from the actual solid angles of each pair of opposite detectors. Asymmetry effects induced by beam misalignment in coincidence with spurious transverse polarization components led to corrections in second order.

Control parameters have been recorded to determine variations in scattering and solid angles for each detector. On-line monitoring of the asymmetries of the reaction $^7Li(\vec{p},\alpha)^4He$ has been performed to check the relation of target current as well as to determine apparative fake

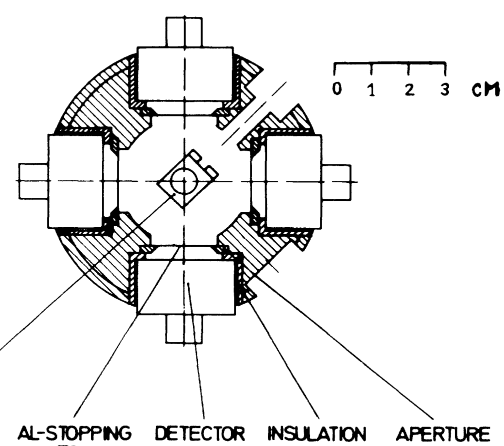

FIG. 1. Vertical cut of the first detector ring.

asymmetries due to beam misalignment induced by switching the polarization; additionally, the latter observable has been used for cross checks of the data. Apparative asymmetries occurring due to spin reversal have been avoided by switching the polarization on and off with a frequency of 62 Hz.

In order to monitor the reaction energy and to correct time dependent carbon built up on target the corresponding γ-ray spectrum has been recorded for each run via the reaction $^{19}F(\vec{p},\alpha\gamma)^{16}O^*$ with a large NaI detector.

The beam polarization has been determined from intermittent measurements with transverse polarization in the same experimental setup via the reaction $^{19}F(\vec{p},\alpha_0)^{16}O$ ($A_y \approx 0.8$; $P = 0.7$; $I_T \approx 300$ nA). The target current ratios were measured in a Faraday cup and additionally determined from the $^7Li(\vec{p},\alpha)^4He$ peak integrals.

The details of the data analysis as well as the size and determination of the individual correction terms are described in Ref. 6. The overall correction led to an increase in error bars of 10–30% (depending on the number of spectra per energy) and shows the dominance of the statistical errors in the data.

Within a net measuring time of 370 h the data for the longitudinal analyzing power (including all statistical uncertainties of the corrections for superimposed residual instrumental and transverse asymmetries) have reached an accuracy of $\Delta A_z \approx 1\times10^{-3}$ for each of the eight energy points. A description of the data by the expected dispersionlike energy behavior,[4] caused by an interference of the PNC amplitude with PC amplitudes at the resonance energy for the $^{20}Ne^*(1^+)$ level, by a two parameter least-squares fit[5-7] results in $A_z = (15.0\pm7.6)\times10^{-4}$ with a probability $P(\chi^2 \geq \chi^2_{\min}) = 67\%$ taking the χ^2+1 criterion for the determination of the quoted error. Figure 2 shows the maximum, optimum, and minimum analyzing power fits to the experimental data, giving no evidence for the theoretically expected large size of the interference effect.

The corresponding α_0 decay width $\Gamma^{PNC}_{\alpha_0}$ can be derived from the formulas of Ref. 4 if pure two-level mixing with the overlapping ($\Delta E = 20$ keV)$J^\pi = 1^-$, $T = 0$ state ($E_x = 13.462$ MeV, $\Gamma = 195$ keV) is assumed. However, the $\mathcal{R}$-matrix analysis of a recent σ and A_y measurement[8] gave support for a reduction of the contribution of this 1^- level to the cross section. Additionally, the possibility of a contribution from a second 1^- level at $E_x = 13.519$ MeV ($\Gamma \approx 33$ keV) as well as a non-negligible influence produced by a direct reaction mechanism may become relevant for the analysis of the interference effect. Therefore, a more general analysis has been developed considering five regular amplitudes ($l_p \leq 2$), which have been

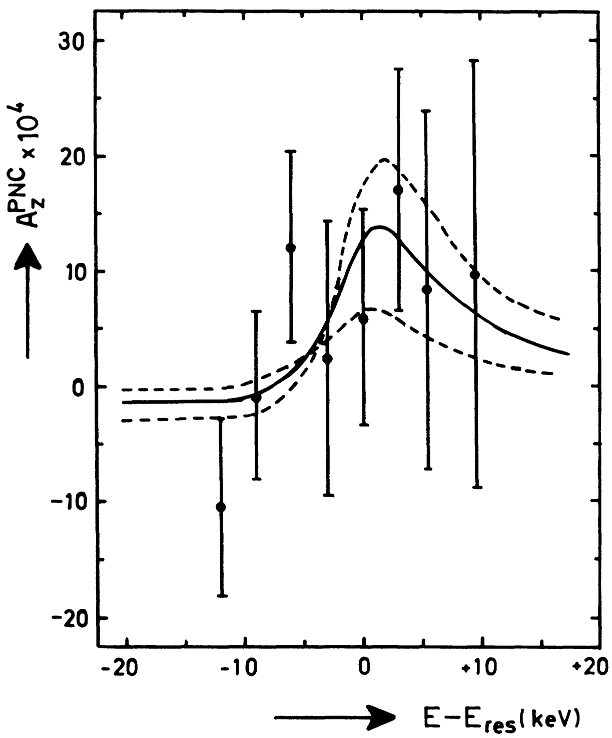

FIG. 2. Experimental results and least-squares fits of the data for maximum, optimum, and minimum longitudinal analyzing power of the reaction $^{19}F(\vec{p},\alpha_0)^{16}O$ vs proton energy around $E_{res}(1^+)$. The error bars indicate one standard deviation and contain all errors due to the corrections of systematic asymmetries.

determined from $\mathcal{R}$-matrix analysis of σ and A_y data for the $^{19}F(\vec{p},\alpha_0)^{16}O$ reaction and one PNC amplitude ($l_p = 0$). The latter one has been determined from a comparison of the result for the longitudinal analyzing power $A_z = (15.0\pm7.6)\times10^{-4}$ with a parametrization of A_z in terms of vector coupling coefficients multiplied by Legendre polynomials. Finally, the irregular α_0 width $\Gamma^{PNC}_{\alpha_0}$ could be obtained without further theoretical assumptions. The details of the analysis are described in Ref. 6.

The main results deduced from the present helicity experiment are summarized in Table I in comparison with new results of an analog analysis,[6] applied to the previously reported experimental data of Refs. 5 and 7. The results for A_z^{PNC} from the new A_z experiment contain a threefold higher statistical accuracy than the data of Ref.

TABLE I. PNC parameters deduced from longitudinal and transverse PNC analyzing powers (A_z, A_x) of the reaction $^{19}F(\vec{p},\alpha_0)^{16}O$ investigating the PNC α_0 decay of the $^{20}Ne^*(1^+, T=1)$ level at $E_x = 13.482$ MeV. (Isovector contributions due to exchange of heavy vector mesons are neglected.)

Ref.	Measured quantity	$A^{PNC}\times10^4$	$(\Gamma^{PNC}_{\alpha_0})^{1/2}\times10^4$ (eV)$^{1/2}$ Two-level analysis	$f_\pi\times10^7$	$(\Gamma^{PNC}_{\alpha_0})^{1/2}\times10^4$ (eV)$^{1/2}$ Multilevel analysis	$f_\pi\times10^7$
6	A_z	15.0 ± 7.6	7.3 ± 4.5	<0.7	23.7 ± 12.4	<2.2
5	A_x	10.0 ± 10.0	5.0 ± 5.9	<0.5	12.5 ± 13.0	<1.3
7	A_z	66.0 ± 24.0	32.8 ± 16.8	<3.0	104.3 ± 40.4	<9.7

7. The new data do not confirm the large PNC effect, found in Ref. 7. Instead, the maximum for A_z is smaller by at least a factor of 2 (68% c.l.). This may arise from the higher statistical accuracy of the present data and from a more precise measurement of the corrections. Furthermore, the present result for $\Gamma_{\alpha_0}^{\mathrm{PNC}}$ rules out the limit, given in Ref. 9 extracted from a σ measurement of the same reaction, as well as the theoretically determined values of Ref. 3 based on a two-level mixing. Therefore, new nuclear structure calculations for the ^{20}Ne compound system (including, e.g., 2 $\hbar\omega$ contributions[10]) would be very helpful to draw more stringent conclusions on the listed PNC parameters. As long as these calculations are not available one presently can obtain values for f_π, e.g., by determination of the enhancement relative to the Cabibbo value for Γ^{PNC} from Ref. 3, since this is based on f_π^{Cab} established by strangeness changing weak hyperon decays, and characterized by a relatively small error interval (see, e.g., Ref. 1). The assumption of a factor of 5 (considered in Table I) for the uncertainty of the predicted value for $\Gamma_{\mathrm{Cab}}^{\mathrm{PNC}}$ produces the main amount of Δf_π, contained in the given upper limits.

Nevertheless, a substantial portion of the theoretically expected DDH interval for f_π would be ruled out with the present limits, if one accepts existing matrix element calculation at face value. Some caution is warranted because 2 $\hbar\omega$ correlations omitted from the ^{20}Ne calculation are known to suppress matrix elements in this mass region. However, pending such calculations in ^{20}Ne, the present interpretation of our experiment is certainly consistent with the limits deduced from five ^{18}F-PNC experiments (see, e.g., Ref. 11) and a recent parametrization also involving experiments with mixtures of different isospin components of the PNC potential.[12] It favors, e.g., the predictions of Ref. 13, weakening the DDH range and best value for f_π.

The ranges of f_π extracted from the present as well as from all previously reported isovector PNC experiments still contain the value $f_\pi = 0$, which leads to the conclusion that the enhancement due to neutral weak current contributions to the weak hadronic interaction seems to be smaller than originally expected from theory, despite unsolved uncertainties from nuclear structure for certain nuclei.

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