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6.6 Parity Mixing of $0^{\pm}$ States in ^{18}F

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Parity nonconservation (PNC) in nuclear systems can be attributed to the $\Delta S=0$ hadronic component of the weak interaction. Nuclear PNC effects at low energy are described in terms of a 2-body potential which results from an effective meson exchange interaction between nucleons in which one vertex is weak and the other strong. Exchanges of π,ρ,ω mesons describe $\Delta I=0,1,2$ components of this interaction; accordingly, 6 amplitudes for weak M-N-N couplings are required to specify the PNC N-N interaction at low energy:

$$h_\rho^0,\ h_\omega^0,\ f_\pi^1,\ h_\rho^1,\ h_\omega^1,\ h_\rho^2 .$$

These amplitudes can be derived from the standard electroweak theory (Weinberg-Salam) within a quark model description of the nucleons and mesons. A few special cases exist in which nuclear structure amplifies otherwise tiny PNC effects and the nuclear wavefunctions are reasonably well known. One such case is the parity-mixed doublet at ~1 MeV in ^{18}F.

In first order perturbation theory, the states at E_x=1042 keV and 1081 keV in ^{18}F are expressed as:

$$|1081\rangle = |0^-,0\rangle + \varepsilon|0^+,1\rangle; \quad |1042\rangle = |0^+,1\rangle - \varepsilon|0^-,0\rangle$$

$$\text{where } \varepsilon = \langle 0^+,1|V_{\Delta T=1}^{PNC}|0^-,0\rangle/\delta E$$

The interference of E1 and M1 transition amplitudes leads to a net circular polarization of γ-rays from these states, given by:

$$P(1042) = 2\varepsilon/R;\ P(1081) = -2\varepsilon R, \text{ where } R = |\langle 0^+\|M1\|1^+\rangle/\langle 0^-\|E1\|1^+\rangle| .$$

The ratio of matrix elements R = 109 ± 12, is deduced from the measured lifetimes of the two states[1]. Thus, P(1081) is strongly enhanced whereas the suppression of P(1042) provides a sensitive test of possible systematic effects. The PNC matrix element in this case is dominated by the long range pion exchange contribution; thus, $|P(1081)| = (13.2 \pm 1.5\ \text{keV}^{-1}) f_\pi^1 |\langle M\rangle|$, where the matrix element $\langle M\rangle = \langle 0^+,1|V_\pi^{PNC}|0^-,0\rangle$ is deduced from a measurement of the forbidden β-decay[1]) : $^{18}Ne(g.s.)\rightarrow{}^{18}F(1081)$. With experimental values, $|P(1081)| = (4.33 \pm 0.87) \times 10^3 f_\pi^1$.

An experiment to measure P(1081) has been performed at Queen's University. The ^{18}F was produced in the reaction $^{16}O(^3He,p)^{18}F$ with a 4.05 MeV beam impinging on a ~1.0 mg/cm^2 Ti foil entrance window (ΔE ~ 0.5 MeV) and a recirculating water target. The γ-ray detection system consists of 4 magnetic transmission polarimeters (at 90°) of permendur alloy 7.2 cm in length with circular polarization sensitivity η = 0.0166 ± 0.0006 at 1081 keV, each backed by a 150 cm^3 intrinsic Ge detector. Beam currents of 10-15 μA on target correspond to detector count rates of 60-70 k/s for E(γ)>100 keV. For the Queen's apparatus the 8-fold ratio:

$$\xi = (U(-,0)D(-,0)L(-,1)R(-,1))/(U(+,1),D(+,1)\ L(+,0)R(+,0))$$

determines the circular polarization of γ-rays at energy E by:

$$P(E)\eta(E)) = (1-\xi^{1/4})/(1+\xi^{1/4}); \quad \text{for small } \eta,\ P\eta \sim (1-\xi)/8$$ where U(-,0) is the number of γ-rays detected in detector U in field status 0, corresponding to electron spins antiparallel to the γ-ray propagation direction.

Gamma-ray events in the energy range ~800-1400 keV were routed into 3 ADC's, amplifier pulses being routed into 1k subspectra of each 8k spectrum according to the detector identity and magnetic field status. The polarimeter fields were reversed every ~10 s, and data were recorded on magnetic tape every ~800 s for 2560 h. All spectra were added together, with gain shift corrections, to produce an 8k 'master' spectrum, 800 channels of which is displayed in fig. 1. The five γ-ray lines are all from decays of states in ^{18}F. Superposed on this figure is ηP_γ for the background regions and peak regions which have been corrected using adjacent background regions of the spectrum. The results are summarized in Table I. (All uncertainties represent one standard deviation in the experimental values.)

Table I. Gamma ray asymmetries in ^{18}F

Transition	E_γ(keV)	$(1-\xi)/8 \times 10^5$
937→g.s.	937	0.63 ± 0.65
2101→1081	1019	-1.07 ± 2.14
1042→g.s.	1042	-0.89 ± 0.88
1081→g.s.	1081	0.27 ± 0.93
2101→937	1164	-0.11 ± 1.64
P(1081)		$(1.6 \pm 5.6) \times 10^{-4}$

Analysis of over 34,000 spectra yields values of the 8-fold ratio with a distribution width within 1% of that calculated from the expected counting statistical fluctuations of each run. Auxiliary experiments and internal checks indicate that systematic uncertainties, due to beam intensity fluctuations and beam steering effects, are an order of magnitude smaller than the statistical uncertainties.

From the data, a value of the weak pion nucleon-nucleon coupling constant f_π^1 is deduced to be $|f_\pi^1| = 0.37^{+1.29}_{-0.37} \times 10^{-7}$. This value is significantly lower than the "best" value of Desplanques et al.[2] and at the lower end of their reasonable range. The above value of f_π^1 is not consistent with that deduced from the ^{21}Ne and ^{19}F PNC[3] experiments. Unlike the ^{18}F case the PNC effects in ^{19}F and ^{21}Ne depend on both isoscalar and isovector coupling terms and the discrepancy may arise from the lack of experimental constraint on the necessary shell model calculations used in the deduction of the isoscalar part in ^{19}F and on both parts in ^{21}Ne. It is hoped that the present work together with other similar experiments in progress will stimulate further theoretical calculations needed to understand the role of the fundamental weak interaction in nuclei.

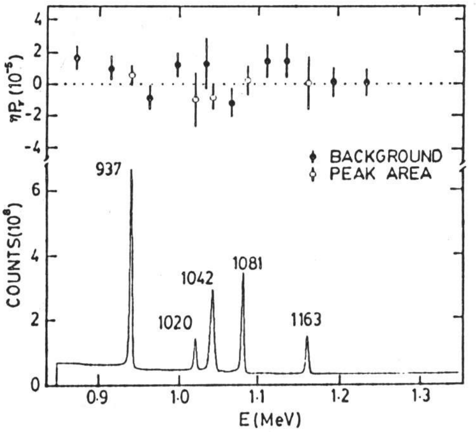

Fig. 1. A portion of the γ-ray spectrum from ^{18}F with superposed asymmetries for peak and background regions.

References

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