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Search for Neutral-Weak-Current Effects in the Nucleus ^{18}F

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The circular polarization of the γ rays from the $1.08 \to 0.0$ MeV transition of ^{18}F has been measured to be $(-0.7 \pm 2.0) \times 10^{-3}$, a value significantly smaller than predicted by recent calculations which include the effects of neutral weak currents.

The discovery of neutral-weak-current effects in reactions induced by high-energy neutrinos[1] has sharply increased interest in theories of neutral currents. One feature that may help distinguish between alternative theories[2] is the $\Delta T = 1$ component of the parity-nonconserving (PNC) nucleon-nucleon weak forces. If neutral weak currents are PNC and isoscalar-isovector mixtures (as in the Weinberg-Salam model), $\Delta T = 1$ parity mixing in nuclei may be enhanced by an order of magnitude over that predicted by the Cabibbo model[3] (charged weak currents only). All previously reported cases of nuclear parity mixing are either insensitive to the $\Delta T = 1$ component of the weak force[4] or do not differentiate between $\Delta T = 1$ and $\Delta T = 0$ or 2 components.[5]

A favorable system for studying the $\Delta T = 1$ PNC nucleon-nucleon force is provided by the 0^-, $T = 0$, 1.08-MeV and 0^+, $T = 1$, 1.04-MeV states of ^{18}F (see Fig. 1).[6] The circular polarization of the 1.08-MeV γ-ray transition from the 0^- state to the ground state directly measures the $\Delta T = 1$ PNC matrix element between the 0^+, $T = 1$ and 0^-, $T = 0$ levels. Since the parity impurity in the 1.08-MeV state is well described by simple two-level mixing with the 1.04-MeV state, the circular polarization P_γ of the 1.08-MeV γ transition is given by

$$P_\gamma(1.08\text{ MeV}) = -2\langle 0^+, T=1 | V^{\text{PNC}} | 0^-, T=0\rangle \times (\|M1\| / \|E1\|)\Delta E^{-1},$$

where $\Delta E = 39$ keV is the energy splitting between the two states, and $\|M1\|$ and $\|E1\|$ denote reduced matrix elements for the $M1$ and $E1$ transitions which de-excite the 1.04- and 1.08-MeV levels.

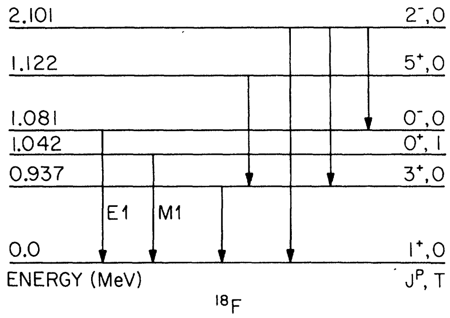

FIG. 1. Energy levels in ^{18}F (not to scale). Only those levels relevant to this experiment are shown.

The two-level mixing approximation is appropriate because $\Delta E = 39$ keV is much smaller than the energy splitting to the next known 0^+ state (≈ 3.7 MeV), and because the 1.04-MeV level has an exceptionally strong matrix element ($\|M1\|/\|E1\| \approx 90$ as determined by the measured lifetimes of the levels).[7] The great speed of the $M1$ decay of the 1.04-MeV level also causes the expected P_γ(1.04 MeV) to be negligibly small.

The layout of our experiment is shown in Fig. 2. Excited ^{18}F nuclei were produced with the reaction $^{16}O(^3He, p)^{18}F^*$ by bombarding a flowing water target with a 10–15-μA beam of 4-MeV $^3He^+$ ions from the Van de Graaff accelerator at the California State University, Los Angeles. The target was part of a closed circulating water system of total volume 20 liters. The flow removed residual ^{18}F activity from the target region and cooled the 7500-Å nickel foil that isolated the water from the vacuum system. The frequency of foil ruptures was reduced to a tolerable level (about three per day) when the beam was diffused over a spot of 3.2 mm diam by passing it through 3 m of low-pressure argon. The P_γ of the γ rays was measured by two transmission-type Compton polarimeters, 8.28 cm long, with iron-alloy cores (65% iron and 35% cobalt). The polarimeters were positioned with their axes in the horizontal

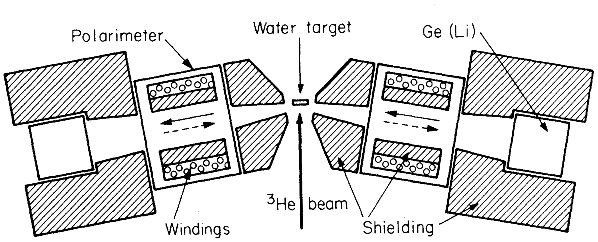

FIG. 2. Schematic layout of the experiment, shown in horizontal section.

plane, at angles of 100° with respect to the beam. The polarimeters contained tungsten shielding to reduce the flux of scattered γ rays seen by the detectors.

Pulse-height spectra from the two 15% Ge(Li) detectors were recorded in separate multichannel analyzers. The spectra for the two possible senses of the polarimeter magnetization, which was reversed every two seconds, were stored in different regions of memory. In addition to the peak corresponding to 1.081-MeV γ rays, the spectra [see Fig. 3(a)] contained peaks from 0.937-, 1.020-, 1.042-, and 1.163-MeV γ rays from ^{18}F which are expected to have negligible circular polarizations. The accumulated spectra were written on magnetic tape, and the memories cleared at intervals of about 2 h, for a total of about 1500 h of counting.

For each of the spectral regions shown in Fig. 3(a), the asymmetry

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

is displayed in Fig. 3(b). In this expression R_-, R_+, L_-, L_+ denote the numbers of counts recorded in a given spectral region by the right or left counter for the (−) and (+) sense of the polarimeter magnetization. To lowest order, A is independent of differences in the efficiencies of the γ-ray detectors, and of beam current fluctua-

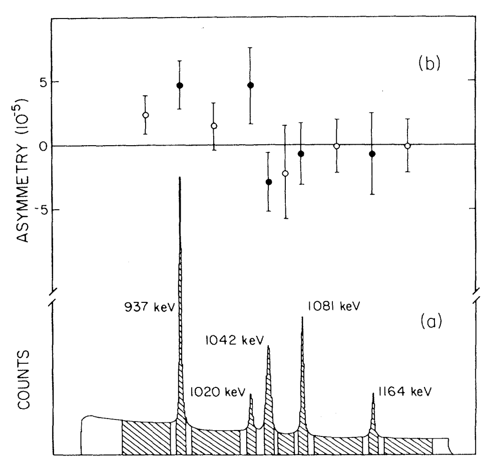

FIG. 3. (a) Typical pulse-height spectrum. The ten spectral regions for which asymmetries were determined are shaded. (b) The measured asymmetries with their statistical standard deviations. The open and closed circles are for the background and peak regions, respectively, shown in (a). For the circular polarization predicted in Ref. 8, an asymmetry of $\pm 11 \times 10^{-5}$ would be expected for the 1081-keV γ rays.

tions. Since the magnetizations of the polarimeters were parallel, the asymmetry is related to the circular polarization by $A = \eta P_\gamma$, where η is the analyzing power of the polarimeters.

η was measured by placing the two polarimeters in series between an intense ^{60}Co source and one Ge(Li) detector. One polarimeter had a constant current and polarized the γ rays; the other was switched and served as analyzer. η was determined to be $(2.39 \pm 0.09) \times 10^{-2}$ and $(2.19 \pm 0.10) \times 10^{-2}$ for γ rays of energy 1.33 and 1.17 MeV, respectively. An extrapolation to 1.08 MeV using known Compton cross sections yields $\eta = (1.88 \pm 0.06) \times 10^{-2}$.

Since the P_γ predicted for the 1.08-MeV γ ray corresponds to an asymmetry less than 10^{-4}, it is necessary to demonstrate that instrumental and other false effects are either insignificantly small or correctable. We have shown that the electronic system does not introduce detectable asymmetries at a level of 10^{-5}, in extensive runs using pulsers or ^{60}Co sources placed at the target site. Energy-dependent asymmetries can be produced by circularly polarized γ rays arising from in-flight annihilation of positrons and positron-induced bremsstrahlung; these asymmetries should be eliminated by the background subtraction procedure described below. In addition, stray magnetic fields in the target region and along the beam path which reverse direction as the sense of the polarimeter magnetization is changed will cause (i) displacements of the centroid of the beam spot on the target; (ii) rotations of the beam about a vertical axis; and (iii) precession of excited ^{18}F nuclei.

To study these three effects we have taken the following measures: (1) The reversing component of the external polarimeter fields was carefully measured at the target site and along the beam path. The magnitudes of the beam displacements, rotations, and precessions of excited ^{18}F states were then calculated and found to cause negligible asymmetries, with the possible exception of the 0.937-MeV γ ray. (2) As an extra precaution, field-compensating coils were mounted on the outside of the polarimeters, and powered in series with them, to reduce the reversing fields along the beam path and at the target. (3) Data were collected with the reversing fields artificially enhanced by a factor of about 100. Because the experimental station was constructed from nonferromagnetic materials, the enhanced-field data may be scaled down to estimate the effects of the reversing magnetic fields. These measurements verify that the external polarimeter fields cannot produce significant asymmetries, except possibly for the 0.937-MeV γ ray, for which the combination of a highly anisotropic angular distribution, and the large g factor and long lifetime of the 5^+ ^{18}F state which feeds into it, may result in a detectable asymmetry. Hence we do not ascribe the small asymmetry of the 0.937-MeV γ ray to circular polarization. Since the asymmetries of the other peaks are completely consistent with the expected statistical fluctuations about zero, there is, in fact, no evidence for circular polarization for any of the γ rays.

We have extracted the asymmetry A_p for the 1.08-MeV peak from the measured asymmetries by means of the expression

$$(1-f)A_p = A_t - fA_b,$$

where $A_t = (-0.7 \pm 2.4) \times 10^{-5}$ is the asymmetry observed for the narrow region of the spectrum that includes both the peak and its underlying background, $f = 0.35$ is the fraction of the total counts in that region that are background counts, and A_b is the asymmetry assumed for the background, as determined from a fit to the measured asymmetries for the five background regions of the spectrum. The values obtained for A_b at the 1.08-MeV peak for assumed constant, linear, and quadratic energy dependences are 10.3 ± 8.8, 4.5 ± 9.5, and -1.0 ± 16.1, respectively, in units of 10^{-6}. These are consistent with one another and with $A_b = 0$. On the basis of the linear fit to the background asymmetries, $A_p = (-1.3 \pm 3.7) \times 10^{-5}$; the other background fits give values for A_p which are not significantly different. Our experimental result is therefore $P_\gamma(1.08 \text{ MeV}) = (-0.7 \pm 2.0) \times 10^{-3}$.

The most recently published calculations of $P_\gamma(1.08 \text{ MeV})$ are by Gari, McGrory, and Offermann[8]. With a weak N-N PNC potential obtained from the Cabibbo model, they predict $P_\gamma^{\text{CC}}(1.08 \text{ MeV}) = \pm 3.6 \times 10^{-4}$. Their neutral-weak-current prediction is $P_\gamma^{\text{NC}}(1.08 \text{ MeV}) = \pm 5.7 \times 10^{-3}$, an enhancement by a factor of 16, and differs from the experimental result by 2.5 or 3.2 standard deviations, depending on the signs of the matrix elements in the expression for $P_\gamma(1.08 \text{ MeV})$. Uncertainties in the theoretical prediction arise from the following: (1) The large uncertainty in the measured lifetime[7] of the 1.04-MeV level (4_{-2}^{+3} fs). However, the lifetime of the 1.04-MeV state can be estimated from the ^{18}F and ^{18}Ne ft values; these yield a value in agreement with experiment but with a much smaller uncertainty.

(2) Uncertainties in the nuclear wave functions. More recent Cabibbo-model predictions[9] of P_γ^{CC}(1.08 MeV) are in qualitative agreement with, and somewhat larger than, the results of Ref. 8. (3) The "enhancement factor" to be expected from the neutral weak currents is difficult to calculate precisely; current estimates[10] for the Weinberg-Salam model point to a value of about 10.

The ^{18}F system is one of the most favorable cases, both experimentally and theoretically, for studying $\Delta T = 1$ PNC forces. With the Cabibbo-model prediction of Ref. 8, the present experiment yields an upper limit of 7.5 for the "enhancement factor" produced by neutral weak currents.[11]

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Resonant Coherent Excitation of Channeled Ions

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We have observed resonant excitation of swift channeled hydrogenlike ions ($Z = 5$ to $Z = 9$) and heliumlike F^{7+} which arises from a coherent periodic perturbation by the atoms in the bounding crystal rows. The resonance excitation was seen through the reduction in the transmission of fixed-charge-state ions through channels in thin crystals of Au and Ag.

A channeled ion passing between ordered rows of atoms in a crystal lattice with a velocity v experiences a coherent periodic perturbation of frequencies $\nu = k(v/d)$, $k = 1, 2, 3, \ldots$, where d is distance between atoms in a row. When one of these frequencies coincides with $\nu_r = \Delta E_{ij}/h$, where ΔE_{ij} is the energy difference between electronic states i and j of the ion, a resonant coherent excitation might occur. This possibility was first pointed out by Okorokov[1] but it requires well-defined states and perhaps this is the reason that previous investigations have yielded negative or,

