P-odd symmetry in the transmission of longitudinally polarized thermal neutrons by uranium-233

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The spatially odd asymmetry in the transmission of a longitudinally polarized beam of thermal neutrons by a uranium-233 sample has been measured. The relative difference between the cross sections for neutrons of opposite helicity is less than or equal to 1×10^{-6}.

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Recent experiments have revealed several neutron-optics phenomena which reflect the weak interaction in nuclear processes. Specifically, the rotation of the polarization plane of a transverse-polarized beam of thermal neutrons by a tin-117 sample has been measured,[1] and the asymmetry in the transmission of longitudinally polarized thermal and resonant neutrons by ^{139}La, ^{117}Sn, ^{81}Br, and ^{111}Cd has been measured.[2,3]

Earlier experiments had revealed a nonconservation of spatial parity in the thermal-neutron fission of ^{233}U, ^{235}U, and ^{239}Pu nuclei.[1]

Common to all these phenomena is a pronounced amplification (by a factor of 10^2–10^5) of the "nucleating" parity-nonconservation effect characteristic of the weak interaction. This nucleating effect is estimated[8] to be[1)]

$$F \sim H_w / \omega \cong Gm_\pi^2 = 2 \times 10^{-7} \;{}^{1)}.$$

Several existing theories (which frequently start from different positions) have generated explanations for this pronounced manifestation of weak forces in nuclear processes.[5–9] There is a need for a more detailed experimental study of P-odd effects in nuclear interactions in order to choose the best theoretical model.

If, for example, we work from the equations of the two-level approximation from Ref. 7 or Ref. 8, we find the following relationship between the values of the P-odd coefficients in fission and transmission:

$$P = \alpha_{nf} \sqrt{\frac{\Gamma_s^f}{\Gamma_p^f}} \frac{E_s\Gamma_p + E_p\Gamma_s}{E_p\Gamma_s} \sqrt{\frac{\Gamma_p^n}{\Gamma_s^n} E \sqrt{E_s / E_p^3}} ,$$

where P is the relative difference between the cross sections for neutrons of opposite helicities; α_{nf} is the P-odd coefficient of the asymmetry in the emission of the fragments in fission by polarized neutrons; Γ_s^f and Γ_p^f are the fission widths for the s and p resonances, respectively; Γ_s and Γ_p are the respective total widths; Γ_s^n and Γ_p^n are the respective neutron widths; E_s and E_p are the energies of the corresponding resonances; and E is the energy of the neutrons. Using the parameters[10,11] of the resonances for the isotope ^{233}U and the value[11] of the P-odd coefficient α_{nf}, we find the relative difference between the cross sections for neutrons of opposite helicities in the thermal energy range to be $P = 5 \times 10^{-5}$.

The present experiments were carried out to determine the value of P for ^{233}U. The measurements were carried out by an integrated—comparison method, analogous to that used in Ref. 2, in the beam of polarized thermal neutrons in the IR-8 reactor at the Kurchatov Institute of Atomic Energy, Moscow. The beam was polarized by reflection from magnetized cobalt mirrors; its total intensity at the sample was 5×10^7 n/s (the polarizer is described in Ref. 12). The degree of polarization was $74.3 \pm 0.5\%$, according to measurements carried out through a direct separation of the oppositely polarized beam components in a very nonuniform magnetic field.[13] The polarization direction was reversed at a frequency of 1 Hz. The spin flipper was of the foil-with-current type.[14]

The neutrons were detected by an array of SNM-16 counters operated in the ionization-chamber regime. These counters were positioned to avoid any changes in the detected current upon possible small movements of the beam (caused by temperature fluctuations, etc.). The currents from the detectors measuring the direct neutron beam and that transmitted through the sample were passed through the same load resistance in opposite directions. The resultant voltage was measured by a highly stable voltmeter which was connected to an É-60 computer for on-line automatic control of the entire experiment. This computer also performed the subsequent analysis of the experimental data.

The direction of the magnetic field "guiding" the spin was reversed every 12 h to eliminate any possible instrumental asymmetry.

The experimental results are listed in Table I. To check the measurement apparatus we also measured the P-odd asymmetry in the transmission of a natural isotopic

TABLE I.

Sample	Exptl. asymmetry ($\times 10^6$)	$P = (\sigma_+ - \sigma_-)/(\sigma_+ + \sigma_-)$ ($\times 10^6$)
KBr	-11.2 ± 1.86	———
Scaled to Br	———	7.9 ± 1.3
^{233}U	-2.00 ± 1.19	1.17 ± 0.69

mixture of bromine. We see that the result agrees well with results published elsewhere.[2]

Comparison of the result found for ^{233}U with the estimate above shows that either the two-level approximation used in finding the estimate is incorrect or the $E = 0.17$ eV level near which the zero crossing of the P-odd coefficient in the emission of the fragments was measured in Ref. 11 is not a p-wave level. In the latter case, the results of Ref. 11 cannot be explained as simply as in Ref. 8.

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[1)]Here H_w is the effective Hamiltonian of the parity-breaking weak interaction of nucleons; $\psi\omega$ is the characteristic energy of the nucleons; FG is the Fermi constant; and m_π is the mass of a π meson (the notation is that of Ref. 8).

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