Violation of spatial parity in the total cross section for interaction of thermal neutrons with plutonium-239 nuclei

L. N. Bondarenko, S. V. Zhukov, and V. L. Kuznetsov
I. V. Kurchatov Institute of Atomic Energy

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The asymmetry of the total cross section for the interaction of thermal neutrons with ^{239}Pu nuclei has been measured: $\mathscr{P}_{th} = (6.66 \pm 1.63) \times 10^{-7}$. A two-level approximation of a dynamic resonant intensification model is used to estimate the total neutron width, $\Gamma_p^n \cong 8 \times 10^{-9}$, and the channel width, $\Gamma_{p1/2}^n \cong 2 \times 10^{-9}$, of a hypothetical 0.7-eV p-resonance.

The existence of P-odd and P-even asymmetries in the emission of the fission fragments of ^{233,235}U and ^{239}Pu nuclei has now been reliably established.[1] According to the present understanding, these nuclei may also exhibit neutrino-optical effects. Attempts to detect nonconservation of P parity in the total cross section for the interaction of thermal neutrons with fissionable nuclei, $\mathscr{P} = (\sigma^+ - \sigma^-)/(\sigma^+ + \sigma^-)$, at the sensitivity level of $\sim 10^{-6}$ proved to be unsuccessful.[2,4] In a previous study[5] we found a limitation on the asymmetry of the total cross section for the interaction of thermal neutrons with ^{233}U nuclei: $\mathscr{P} \leqslant 2.7 \times 10^{-7}$ at the 90% confidence level. To answer the question whether the slight asymmetry of the total cross section of ^{233}U is attributable to the random features of the ^{234}U compound nucleus levels or to a property common to fissionable nuclei, we measured the asymmetry of the total cross section for the interaction of thermal neutrons with ^{235,238}U and ^{239}Pu nuclei.

The measurements were carried out by the integral comparison method using a thermal neutron beam[6] from the IR-8 reactor of the I. V. Kurchatov Institute of Atomic Energy. The experimental arrangement is described elsewhere.[5,7]

The instrumental asymmetry was measured with a neutron beam which was blocked by a 1-mm-thick cadmium plate; i.e., it was measured with > 0.5-eV neutrons. In this energy region the analyzing capacity of iron magnetized to saturation is nearly zero, so that this effect is absent.

The measurements of the P-odd transmission asymmetry and the possible instrumental asymmetry, "$\mathscr{P} + Z$," were alternated with the epicadmium-neutron measurements of the instrumental asymmetry Z. The final result for the relative asymmetry of the total cross section $\mathscr{P}$ was observed by subtracting Z from $\mathscr{P} + Z$, and its error is equal to the quadratic sum of the mean-square errors.

To verify the sensitivity, we repeated the measurements of the polarization of the neutron beam, P_N, after its transmission through the KBr sample of thickness 0.083 unit of the mean free path of neutrons. The value which we obtained, $P = (9.9 \pm 2.4) \times 10^{-7}$ is in good agreement with the measurements carried out pre-

TABLE I. The results of measurements of the weak polarization of the neutron beam produced as a result of weak interaction of neutrons with nuclei of the test sample and the total neutron cross section asymmetry corresponding to this polarization.

Sample	$n\sigma$	$P_n \cdot 10^7$	$\mathcal{P} \cdot 10^7$
^{238}U	1.76	− 3.91 ± 3.03	− 2.22 ± 1.72
^{235}U	2.44	2.18 ± 4.51	0.89 ± 1.85
^{239}Pu	1.98	13.19 ± 3.23	6.66 ± 1.63
^{239}Pu	—	—	− 11.0 ± 12.0(Ref. 4)
KBr	0.083	9.9 ± 2.4	—
KBr	0.083	10.8 ± 1.2	— (Ref. 5)

viously[5]: $P = (10.8 \pm 1.2) \times 10^{-7}$. The results of all measurements are presented in Table I. The ^{235}U and ^{238}U nuclei showed no evidence of P-odd asymmetry in the total neutron-nucleus cross section within the measurement error, $\sim 2 \times 10^{-7}$. The results of these measurements and the result of the measurement with the ^{233}U sample are a test of the "null effect." The result of the only attempt to measure $\mathcal{P}$(^{239}Pu) is also given in Table I.

The presence of P-odd asymmetry in the total cross section for the interaction of thermal neutrons with ^{239}Pu nuclei is evidence that there is a p resonance with a relatively large channel width, $\Gamma^n_{p1/2}$, near the thermal neutron energies. Further analysis requires the p-resonance energy to be estimated. The P-odd asymmetry of the separation of fragments, $A_{(s_n p_p)}$, was measured in Refs. 8 and 9 as a function of the incident neutron energy. Averaging the results of the two studies and extrapolating the shape of the $A_{(s_n p_f)}$ curve to the point at which it crosses the abscissa, we estimate the p-resonance energy to be ~ 0.7 eV.

At thermal neutron energies the P-odd asymmetry of the total cross section $\mathcal{P}$ can be expressed in terms of the P-odd fragment-separation asymmetry[10] $A_{(s_n p_f)}$:

$$\mathcal{P} \cong A_{(s_n p_f)} \sqrt{\Gamma^f_s / \Gamma^f_p}\, \frac{\Gamma_s E_p + \Gamma_p E_s}{\Gamma_s E_p} \left(\frac{\Gamma^n_{p1/2}}{\Gamma^n_s} \sqrt{E_s / E_p} \right)^{1/2} \sqrt{E_{th} / E_p}.$$

It is assumed everywhere that Γ_p, Γ_s, Γ^n_p, Γ^n_s, Γ^f_p, and Γ^f_s are the total width, the neutron width, and the fission width of the p and s resonances, and E_p and E_s are their energies. Setting $\Gamma^f_s \cong \Gamma^f_p$ and $\Gamma_s \cong \Gamma_p \cong 0.1$ eV and making use of the fragment separation asymmetry for ^{239}Pu, averaged over the data in the literature,[1] $A_{(s_n p_f)} = 6.5 \times 10^{-4}$, we estimate the channel width to be $\Gamma^n_{p1/2} = 2.0 \times 10^{-9}$ eV.

At 0.7 eV the total neutron width Γ^n_p of the p resonance can be estimated from the known value of the P-even, left-right, fragment-separation asymmetry,[11] $A_{p_f[p_n s_n]} = (1.25 \pm 0.29) \times 10^{-4}$, and from the expression for this asymmetry in terms of the resonance parameters[10]

$$A_{p_f[p_n s_n]} \cong \left(\frac{\Gamma_p^f \Gamma_p^n}{\Gamma_s^f \Gamma_s^n} \sqrt{\frac{E_s}{E_p}} \right)^{1/2} \frac{\Gamma_s E_p - \Gamma_p E_s}{E_p^2} \sqrt{\frac{E_{th}}{E_p}}.$$

Setting $\Gamma_p^f \cong \Gamma_s^f$, $\Gamma_p \cong \Gamma_s \cong 0.1$ eV, and $E_{th} = 0.03$ eV, as in the previous case, we estimate the total neutron width to be $\Gamma_p \cong 8.0 \times 10^{-9}$ eV.

The estimates of the total neutron width Γ_p^n and the channel width $\Gamma_{p1/2}^n$ of the hypothetical 0.7-eV resonance are in agreement with each other. To determine the *p*-resonance parameters more accurately, however, the *P*-odd asymmetry of the total cross section for the interaction of neutrons with ^{239}Pu nuclei at neutron energies 0.6–0.9 eV should be measured. The value of $\mathscr{P}$ in the *p* resonance is expected to be on the order of 10^{-3}.

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