Left-right asymmetry in the γ emission at a *P*-parity-breaking neutron resonance of ^{117}Sn

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Pis'ma Zh. Eksp. Teor. Fiz. **39**, No. 8, 346–348 (25 April 1984)

A left-right asymmetry in the emission of γ rays ($E_\gamma = 9.32$ MeV) in the radiative capture of polarized neutrons has been observed for the first time at the 1.33-eV *p*-wave neutron resonance in ^{117}Sn. The value $\Gamma^n_{p1/2}/\Gamma^n_p = 0.27 \pm 0.03$ has been found for the relative partial neutron width corresponding to the channel with a total neutron spin $j = 1/2$.

The *P*-odd effects which are observed in the interaction of slow neutrons with complex nuclei are presently attributed to a mixing of levels of different parity because of a weak interaction between nucleons.[1] In the neutron cross sections *s*- and *p*-wave resonances correspond to these nuclear levels. The magnitudes of the effects are related to the matrix elements of the weak interaction taken between the levels that are mixed and to the parameters of the corresponding resonances, including the amplitude of the partial neutron width, $\sqrt{\Gamma^n_{p1/2}}$. This amplitude corresponds to the excitation of a *p*-wave resonance by neutrons with a total angular momentum $j = l + s_n = 1/2$; the total width is $\Gamma^n_p = \Gamma^n_{p1/2} + \Gamma^n_{p3/2}$. Information on the partial neutron widths can be obtained by studying the angular distributions of reactions induced by neutrons. For weak p-wave resonances, however, no information of this sort is available.

In the present experiments we implemented a new method for determining the partial neutron widths of p-wave resonances in a study of the left-right asymmetry in the emission of γ rays produced in the radiative capture of neutrons polarized perpendicular to the reaction plane. This asymmetry results from an interference between resonances of different parities, which gives rise to several interference terms in the differential cross section for the (n, γ) reaction[2]:

$$\sigma(\theta, \varphi) = a_0 + a_1(\mathbf{k}_n \mathbf{k}_\gamma) + a_2 \mathbf{s}[\mathbf{k}_n \times \mathbf{k}_\gamma] + a_3[(\mathbf{k}_n \mathbf{k}_\gamma) - \frac{1}{3}] \quad . \tag{1}$$

Here $\mathbf{s}$, $\mathbf{k}_n$, and $\mathbf{k}_\gamma$ are unit vectors along the directions of the neutron spin, the neutron momentum, and the γ momentum, respectively. The coefficients a_0–a_3 are known functions of the parameters of the resonances and of the neutron energy. If the experiment is carried out in the geometry $s \perp [\mathbf{k}_n, \mathbf{k}_\gamma] \mathbf{k}_n \perp \mathbf{k}_\gamma$, the second term in (1) vanishes, while the third changes sign when the spin is flipped. In this case we find the following expression for the effect, $\epsilon_\gamma = (\sigma^\uparrow - \sigma^\downarrow)/(\sigma^\uparrow + \sigma^\downarrow)$, using the method of Ref. 2:

$$\epsilon_\gamma(90^\circ) \quad \frac{\frac{1}{2}\Gamma_a\left(\Gamma_p + \frac{E - E_p}{|E_s|}\Gamma_s\right)\left(x + \frac{1}{2\sqrt{2}}y\right)}{(E - Ep)^2 + \frac{1}{4}\left[\Gamma_p^2 + \Gamma_q^2\left(1 + \frac{1}{\sqrt{2}}xy + \frac{1}{4}y^2\right)\right]} \quad . \tag{2}$$

Here E is the neutron energy, $\Gamma_a = 2|E_s|\sqrt{(\Gamma_p^n/\Gamma_s^n)(\Gamma_p^{\gamma i}/\Gamma_s^{\gamma i})}$, and the subscripts "$s$" and "$p$" specify the neutron resonances in the s and p waves, repectively. We are to determine $x = \sqrt{\Gamma_{p1/2}^n/\Gamma_p^n}$ and $y = \sqrt{\Gamma_{p3/2}^n/\Gamma_p^n}$ $(x^2 + y^2 = 1)$.

In the present experiments we studied the resonance at 1.33 eV in ^{117}Sn; several P-odd effects which have been observed have been associated with this resonance. The measurements were carried out by a time-of-flight method in the pulsed IBR-30 reactor of the Neutron Physics Laboratory of the Joint Institute for Nuclear Research. The beam polarization and the reversal of this polarization have been described previously.[3] A beam with a vertical polarization, perpendicular to the neutron momentum, was directed to a tin target with a mass of 240 g (92% ^{117}Sn). The γ detector was a NaI (Tl) crystal positioned in the horizontal plane, perpendicular to the direction of the neutron beam. This crystal was 200 mm in diameter and 200 mm thick. The solid angle subtended at the detector was 3.5×10^{-2} of 4π sr. The pulse detection threshold was set at 8.5 meV for detection of the line with the energy $E_\gamma = 9.32$ MeV, which is the hardest line in the γ spectrum. The detector was shielded with lead, paraffin, and boron carbide to reduce the background. The background was measured with an equivalent scatterer in the place of the working sample.

The experimental results are shown in Fig. 1 as plots of the quantities $N^\uparrow$, $N^\downarrow$ and $\epsilon_\gamma(90^\circ) = (N^\uparrow - N^\downarrow)/(N^\uparrow + N^\downarrow)f_n$ vs the time of flight. Here f_n is the beam polarization, and $N^\uparrow$ and $N^\downarrow$ are the detector count rates for the up and down beam polarizations, respectively, after subtraction of the background. Equation (2) with the experi-

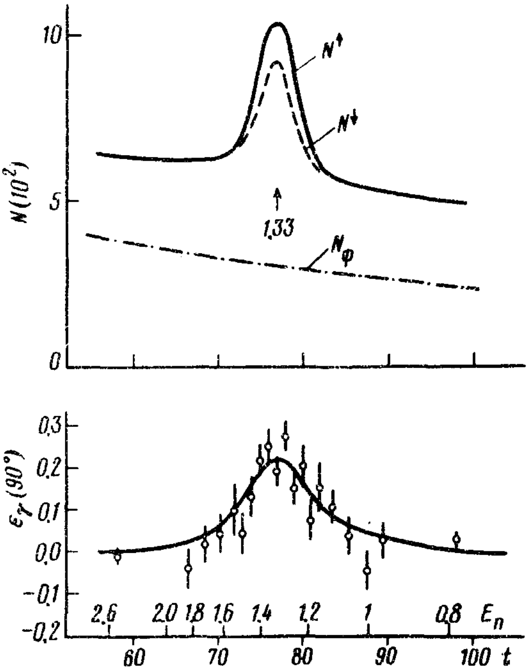

FIG. 1. A left-right asymmetry in the emission of γ rays ($E_\gamma = 9.32$ MeV) in the radiative capture of polarized neutrons has been observed for the first time at the p-wave 1.33-eV neutron resonance in ^{117}Sn. The value $\Gamma^n_{p1/2}/\Gamma^n_p = 0.27 \pm 0.03$ has been found for the relative partial neutron width corresponding to the channel with a total neutron spin $j = 1/2$.

mental value of ϵ_γ was solved numerically by the method of least squares. In these calculations we used the resonance parameters $\Gamma_s = 0.1$ eV $\Gamma_p = 0.23$ eV (Ref. 3), $\Gamma^n_p = 2.5\times10^{-7}$eV (Ref. 3), $\Gamma^{\gamma i}_p/\Gamma^{\gamma i}_s = 0.5$ (Ref. 4), and $|E_s| = 29$ eV. We also used the reduced neutron width $\Gamma^{n0}_s = 3.5\times10^{-3}$ eV, refined on the basis of measurements of the cross section for the capture of thermal neutrons by the isotope ^{117}Sn (Ref. 4). We found the four x, y pairs listed in Table I.

The pairs with the small values of x seem nonphysical, since they lead to contradictions in the matrix elements found for the weak interaction through the use of various P-odd effects which have been observed experimentally. At present, on the basis of the data available, we cannot choose between pairs I and II. They correspond

TABLE I.

№	x	y
I (II)	+(−) 0.52 ± 0.03	− (+) 0.85 ± 0.02
III (IV)	+(−) 0.090 ± 0.024	− (+) 0.996 ± 0.015

to the same relative partial neutron width of the 1.33-eV resonance: $\Gamma^n_{p1/2}/\Gamma^n_p = 0.27 \pm 0.03$.

With this information on $\Gamma^n_{p1/2}$ and data[4] on the partial γ widths, it becomes possible to carry out a joint analysis of the experimental results of Refs. 5–8 on parity nonconservation in the ^{117}Sn nucleus.

We wish to thank G. S. Samosvat, O. P. Sushkov, V. V. Flambaum, and I. S. Shapiro for useful discussions.

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Translated by Dave Parsons
Edited by S. J. Amoretty