# MEASUREMENT OF THE LEFT-RIGHT ASYMMETRY IN INTEGRAL SPECTRA OF γ -QUANTA IN THE INTERACTION OF NUCLEI WITH POLARIZED THERMAL NEUTRONS

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## Introduction

Work [1] suggests an expression for the cross-section $d\sigma/d\Omega$ of the (n,γ)-reaction; this expression includes 17 correlations. Effects of P-odd $a_9(\vec{\sigma}_n \cdot \vec{p}_\gamma)$ and left-right $a_2(\vec{\sigma}_n \cdot [\vec{p}_n \times \vec{p}_\gamma])$ asymmetry as well as P-odd circular polarization $a_{13}\lambda$ arise due to the interference of γ-transitions between states of different parity; they are enhanced in the vicinity of p-resonances. Nuclei levels of different parity are mixed; the mixing is proportional to the reversal difference between the levels. In the two-resonance approximation, P-odd asymmetry, left-right asymmetry and P-odd circular polarization are related to each other in accordance with [1]. The notations of the correlation coefficients $a_i$ follow those in work [1]. We will denote below $a_{P-odd} = a_9$, $a_{lr} = a_2$ and $P_\gamma = a_{13}$.

P-odd asymmetry effects are of the order of ~$10^{-4}$ for selected γ-transitions. Observation of so small effects is always a complicated task and usually it is possible only due to specific enhancement of these effects by 2-3 orders of magnitude. Enhancement of a P-odd effect and of an effect of left-right asymmetry occurs in the same way. In accordance with [1], both in the vicinity of a p-resonance and far from it, the resonance mechanism dominates for transitions to complex final states. Direct and resonance contributions provide comparable contributions only for transitions into the ground, and close-to-ground, states. Work [1] accounts for both direct and resonance mechanisms. This calculation is valid for any photon multi-polarity. For simplification, the authors took into account only E1- and M1-amplitudes, which dominate in the (n,γ)-reaction. Coefficients for different correlations were calculated in [1] for a monochromatic γ-transition in the reactor of neutrons with $^{117}$Sn. This work shows that estimated coefficients of P-odd asymmetry, P-odd circular polarization and P-odd left-right asymmetry are nearly equal to each other for a selected line in $^{117}$Sn at the thermal neutron energy. As coefficients for other nuclei were not evaluated, we will assume that the ratio of coefficients for other nuclei is equal to that for the $^{117}$Sn line.

P-odd effects for a single γ-transition have been rarely observed because of complexity of selection of a γ-transition also because of smallness of these effects. P-odd asymmetry has been observed in the following reactions with polarized neutrons:

$^{113}Cd(n,\gamma)^{114}Cd$, the energy of γ-transition is ($1^+ \xrightarrow{M1} 0^+$) 9.04 МэВ:

$$a_{P-odd} = (4.1 \pm 0.8) \cdot 10^{-4} \text{ [2];}$$

$^{117}Sn(n,\gamma)^{118}Sn$, the energy of γ-transition is ($1^+ \xrightarrow{M1} 0^+$) 9.31 MэВ:

$$a_{P-odd} = (8.1 \pm 1.3) \cdot 10^{-4} \text{ [3];}$$

$^{35}Cl(n,\gamma)^{36}Cl$, the energy of γ-transition is ($2^- \xrightarrow{M1+E2} 2^+$) 8.58 MэВ:

$$a_{P-odd} = (1.57 \pm 0.53) \cdot 10^{-4} \text{ [4].}$$

Angular correlation was observed usually in integral spectra of γ-quanta, in particular P-odd asymmetry (correlation $(\vec{\sigma}_n \cdot \vec{p}_\gamma)$) and P-odd circular polarization (correlation λ). The number of nuclei, for which a P-odd effect has been observed, is a bit higher than ten; and these are observations of P-odd asymmetry of γ-quanta using the integral method, in which an effect is measured in the complete γ-quanta spectrum.

The sign of coefficients of P-odd asymmetry $a_{P-odd}(\vec{\sigma}_n \cdot \vec{p}_\gamma)$, of left-right asymmetry $a_{lr}(\vec{\sigma}_n \cdot [\vec{p}_n \times \vec{p}_\gamma])$ and P-odd circular polarization $P_\gamma \lambda$ varies randomly as a function of the final nuclear state in accordance with [1]; thus the effects are statistically suppressed down to $O(\varepsilon)$. Effects in integral spectra of γ-quanta are suppressed due to this averaging; however their observation is feasible due to high counting statistics. Calculations [1] show that the ratio of the coefficients of P-odd and left-right asymmetry for a monochromatic line should coincide with the ratio of the coefficients of these asymmetries in integral spectra. The example of $^{117}Sn$ indicates that P-odd effects for a single γ-transition are about equal to the effects of left-right asymmetry at the thermal energy.

## Experimental results

P-odd and left-right asymmetry was measured at various times using thermal and cold polarized neutrons from horizontal and vertical beams at the reactor VVR-M at the PNPI (Gatchina), and also at the PF1B facility at the ILL (Grenoble); the integral method of measurement was always used [5]. The mean neutron energy was different for the different beams. At the horizontal neutron beam at the reactor VVR-M the mean neutron wavelength was 2.7 Å (the energy E=0.011 eV); at the vertical neutron beam at the reactor VVR-M it was 4.2 Å ($E=4.6 \cdot 10^{-3}$ eV), and the PF1B facility at the ILL provided the mean neutron wavelength of 4.7 Å ($E=3.7 \cdot 10^{-3}$ eV).

Physical and chemical states of matter were identical in these measurements of P-odd and left-right asymmetry. The left-right and P-odd asymmetry was measured with the same detectors and targets, at the same background conditions, and with the same solid angles to the detector. The guiding magnetic field was set with the angular accuracy of ±3-5 degrees, thus the correction for the admixture of the P-odd effect to the left-right asymmetry was below 5%. The neutron polarization was 0.92 – 0.97 for different neutron beams. For every target, the polarization was equal in measurements of P-odd and left-right asymmetry.

The values of coefficients of P-odd asymmetry $a_{P-odd}$ are given in the table; the coefficients of P-odd circular polarization $P_\gamma$ are copied from works [6, 7]; and the values of the coefficients of left-right asymmetry are preliminary. P-odd circular polarization was measured at the reactor VVR-M using the installation for measuring circular polarization in the reaction $np \to d\gamma$ with unpolarized neutrons. The measured results are corrected to the neutron polarization and to the solid angle to the detector; the background is taken into account. $E_p$ is the energy of the p-resonance.

| Nucleus | $E_p$, eV | $P_\gamma \cdot 10^6$ [6] | $a_{P-odd} \cdot 10^6$ | $a_{lr} \cdot 10^6$ |
|---|---|---|---|---|
| $^{nat}Cl$ | 398 | $64 \pm 5$ | $-27.6 \pm 4.9$ [6]* | $-3.5 \pm 2.9$ * |
| $^{nat}Br$ | 0.88 | $31 \pm 2$ | $-19.5 \pm 1.6$ [6]* | $-6.5 \pm 1.7$ * |
| $^{nat}La$ | 0.75 | $-160 \pm 25$ | $-17.8 \pm 2.2$ [6]* | $3.9 \pm 3.3$ * |
| $^{nat}Fe$ | 11.47 | - | $4.04 \pm 0.83$ [7]** | $5.4 \pm 5.5$ * |
| $^{117}Sn$ | 1.33 | $19 \pm 5$ (nat) | $2.4 \pm 1.6$ [6]* | $0.9 \pm 4.1$ * |
| $^{nat}Cd$ | 7 | $< 3$ | $1.64 \pm 0.36$ [7]**<br>$2.52 \pm 0.46$ *** | -<br>- |

*The reactor VVR-M in Gatchina (the mean neutron wavelength is 2.7 Å)
** The reactor VVR-M in Gatchina (4.2 Å)
***The reactor ILL in Grenoble (4.7 Å)

The given results show that in all cases with non-zero P-odd asymmetry observed, the coefficient of left-right asymmetry appeared to be much smaller than the coefficient of P-odd asymmetry. On the other hand, in accordance with [1], these coefficients should be approximately equal for integral spectra at the thermal neutron energy for the same nucleus.

**Discussion of the results**

P-odd circular polarization does not depend on the spin factor in contrast to P-odd end left-right asymmetry. Concerning the ratio of the values of P-odd and left-right asymmetry: if a γ-quantum is emitted not to the ground state after neutron capture then at least one more γ-quantum (or several γ-quanta) will be emitted; this fact should decrease P-odd effects but it also equally should decrease the effect of left-right asymmetry thus the ratio should not change. In those cases where the target contains several isotopes, the values of the correlation coefficients should decrease compared to those in the case of mono-isotope; this fact should not change the ratio between P-odd and left-right asymmetry.

In the framework of the statistical model of averaging the effects of P-odd and left-right asymmetry, one does not see any reasons which cause these effects to average differently.

There is no reliable measurement of the coefficient of left-right asymmetry for γ-quanta for nuclei with a p-resonance close to the thermal energy, where there is a significant resonance enhancement in the interaction of a nucleus with thermal polarized neutrons. At the same time there are measurements of the P-odd and left-right asymmetry in the reaction $^{35}Cl(n,p)^{35}S$ with the proton emission. The coefficient of P-odd and left-right asymmetries are equal respectively [8]

$$a_{P-odd} = (-1.51 \pm 0.34) \cdot 10^{-4}, \qquad a_{lr} = (-2.40 \pm 0.43) \cdot 10^{-4}$$

Thus the ratio of the coefficients of P-odd and left-right asymmetry of proton emission in the reaction $^{35}Cl(n,p)^{35}S$ is compatible to unity.

Measurement of the P-odd asymmetry in the line $E_\gamma$ =8.58 MeV in the reaction $^{35}Cl(n,\gamma)^{36}Cl$ provided the value of the asymmetry coefficients $a_{P-odd} = (1.57 \pm 0.53) \cdot 10^{-4}$ [4]. The values of the coefficients of P-odd asymmetry in the reaction with emission of protons and γ-quanta coincide. This coincidence indicates that the value of the coefficient of left-right asymmetry in this (n,γ) reaction should be $a_{lr} \sim 1\cdot 10^{-4}$.

Thus, for the accuracy of the measurement of the left-right asymmetry achieved in this experiment one could use the calculation performed for $^{117}$Sn [1], and one could assume the calculated ratio of the coefficients of P-odd and left-right asymmetry to be about one.

Left-right asymmetry of γ-quanta has not been reliably observed in any studied nucleus except for bromium. As the measured values of the coefficients $a_{lr}$ of left-right asymmetry are much smaller for $^{nat}$La , $^{nat}$Cl, $^{nat}$Br than expected from calculations one has to continue these investigations at beams with high neutron fluxes in order to get statistically significant results for the coefficients of left-right asymmetry as well as to understand the reasons for the discrepancy between calculations and experiments.

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