Investigation of spatial parity breakdown effects in thermal polarized neutron capture reactions with the release of heavy charged particles

N. V. Borovikova,[1] V. A. Vesna,[1] A. I. Egorov,[1] V. A. Knyaz'kov,[1] A. Kolomenskii,[1] V. M. Lobashev,[1,2] A. N. Pirozhkov,[1] L. A. Popeko,[1] L. M. Smotritskii,[1] N. A. Titov[2] and A.I. Shablii[1]

(Submitted 17 August 1979)
Pis'ma Zh. Eksp. Teor. Fiz. **30**, No. 8, 527–532 (20 October 1979)

The value of the *P*-odd asymmetry coefficient of the fragment emission in the fission of ^{235}U through the capture of thermal polarized neutrons has been measured by the integral method. The asymmetry coefficient is equal to $(0.84 \pm 0.06)\times 10^{-4}$. The restriction on the *P*-odd asymmetry in the reactions $^{10}B(n,\alpha)^7Li$: $|\alpha| < 0.5\times 10^{-5}$ and $^6Li(n,t)^4He$: $|\alpha| < 1.0\times 10^{-5}$ are obtained (90% confidence level). A right-left asymmetry has been found in the $^6Li(n,t)^4He$ reaction; the asymmetry coefficient is equal to $(0.95 \pm 0.4)\times 10^{-4}$.

PACS numbers: 25.85.Ec

One of the evidences of a weak nucleon-nucleon interaction is the asymmetry of the emission of the charged particle with respect to the spin of the polarized thermal neutron captured by the nucleus.

The difficulty of such an experiment is the need to ensure the statistical accuracy of the measurements at the $10^{-5} - 10^{-7}$ level. In the set-up of the usual counting experiment the possibilities of increasing the counting rate are limited. The limitation can be removed by making use of the difference in the ranges of the light and heavy reaction products. By choosing the gas pressure between the target and detector one can achieve detection of the light fragment only. Therefore one can use the integral detection method, previously developed at the B.P. Konstantinov Leningrad Institute of Nuclear Physics (LIYaF) for measuring the circular polarization of the γ quanta emitted by unpolarized nuclei.[1]

The measurements were made on the thermal polarized neutron beam of the VVR-M reactor at the LIYaF with an intensity of 6×10^7 neutrons/sec[2].

A fast flipper, using adiabatic flipping of the neutron spin in crossed constant and varying magnetic fields,[3] was employed to change the neutron polarization with respect to the guiding field.

Multifilament proportional counters, shown in Fig. 1, are used as the detector. The neutron beam strikes the target, located along the beam in a common housing with the counters. When the *P*-odd asymmetry is being studied, the neutrons are polarized in the plane of the figure perpendicularly to the beam axis. The gas pressure is chosen such that only the light reaction products reach the volume separated by the wire 4 and solid 5 electrodes. The shielding action of the grid 4 makes the counters insensitive to ionization, isolated outside the space between electrodes 4 and 5.

 0021-3640/80/200495-06$00.60

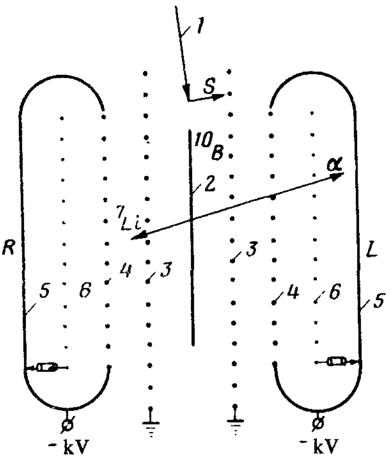

FIG. 1. Reaction product detection scheme: R and L—right and left proportional counters, 1—neutron beam, 2—target, 3—ground-potential wire electrode, 4,5—wire and solid high-potential electrodes, 6—multi-filament signal electrode at low potential with respect to chamber housing.

The current of the detectors is converted into a voltage, amplified and goes to a differential amplifier (the effect we are looking for has opposite signs in both detectors). The resulting signal is integrated during second intervals; at the end of each integration cycle the output voltage of the integrator is converted into digital code and stored.

Titanium foils were used as the substrates for application to the target. The target surface was covered with a second foil in order to equalize the particle spectra in both halves of the chamber. A standard converter was used in the measurements with the uranium oxide U_3O_8.

The flipping of the neutron spin with respect to the guiding field is accomplished by a high-frequency flipper with a 4-second period. The direction of the neutron spin (together with the guiding field) was periodically reversed (about every 24 hours). The sign of the effect we are looking for, associated with the polarization of the neutrons, thus changed as a function of the guiding field in the chamber. This made it possible to eliminate possible systematic effects. The measured effect can be represented in the following manner:

$$a = \frac{(I_L - I_R)_1 - (I_L - I_R)_2}{(I_L - I_R)_1 + (I_L - I_R)_2}, \tag{1}$$

where I_L and I_R are, respectively, the currents of the left and right counter, the subscripts 1 and 2 refer to the flipper status: off (neutron spin is directed along the guiding field) and on (neutron spin opposite to the field).

The measured asymmetry is related to the P-odd term in the angular distribution of the reaction products:

$$w \sim (1 + a\vec{\sigma}\mathbf{p}_l), \tag{2}$$

TABLE I

Reaction	Target, mg/cm²	$\alpha^{+}\cdot 10^{+5}$	$\alpha^{-}\cdot 10^{+5}$	$\bar{\alpha}\cdot 10^{+5}$	$\overline{(\vec{\sigma} p_l)}$	$\alpha\cdot 10^{5}$
$^{10}B(n, \alpha)^{7}Li$	0.1Ti – 0.25B – 0.1Ti	–0.27 ± 0.21	–0.11 ± 0.21	–0.08 ± 0.15	0.62	0.13 ± 0.24
$^{6}Li(n, t)^{4}He$	0.2Ti – 1Li – 0.2Ti	0.33 ± 0.38	0.72 ± 0.55	–0.20 ± 0.33	0.75	–0.27 ± 0.45
$^{6}Li(n, t)^{4}He$ *	–"–	—	–0.60 ± 0.63	0.60 ± 0.63**	0.75	0.82 ± 0.87 *
$^{235}U(n, f)$ (in the form of U_3O_8)	0.35U – 50Al – 0.35U	6.6 ± 0.8	—	7.3 ± 1.7***	0.89	8.5 ± 2.0
$^{235}U(n, f)$* (in the form of U_3O_8)*	–"–	–0.5 ± 1.5	—	—	0.89	
^{235}U (β decay of fragments)	–"–	0.4 ± 0.7	—	—		
$^{235}U(n, f)$ (in the form of UF_4)	0.25Ti – 0.5U – 0.2Ti	10.4 ± 1.2	–4.0 ± 1.0	7.2 ± 0.8	0.90	8.2 ± 0.9
$^{235}U(n, f)$ * (in the form of UF_4)	–"–	1.3 ± 1.1	–0.4 ± 1.4	0.6 ± 0.9 **	0.90	0.7 ± 1.0 *
$^{235}U(n, f)$ (in the form of UF_4)	–"–	8.4 ± 1.2	–6.8 ± 1.3	7.6 ± 0.9	0.90	8.7 ± 1.0
$^{235}U(n, f)$* (in the form of UF_4)	–"–	–1.9 ± 2.2	–0.3 ± 1.8	–0.9 ± 1.4 **	0.90	–1.1 ± 1.6 *

* Beam is depolarized

** Average value of α^{+} and α^{-}.

*** Asymmetry value in depolarized beam has been taken into account (5th line).

where $\boldsymbol{\sigma}$, $\mathbf{p}_l$ are unit vectors in the direction of the neutron spin and the momentum of the light fragment.

The conversion from α to a is made with the beam polarization $P=97\%$ and the dependence of the energy delivered to the detector on the angle between $\boldsymbol{\sigma}$ and $\mathbf{p}_l$ taken into account. The measurement results are listed in Table I, where α^+ is the asymmetry, the guiding field from the right to the left detector; α^- is the asymmetry, the guiding field from the left detector to the right; $\bar{\alpha}=(\alpha^+ - \alpha^-)/2$ is the average value of the asymmetry; $\overline{(\boldsymbol{\sigma}\cdot\mathbf{p}_l)}$ is the average cosine of the angle between $\boldsymbol{\sigma}$ and $\mathbf{p}_l$; $a=\bar{\alpha}/P\overline{(\boldsymbol{\sigma}\cdot\mathbf{p}_l)}$ is the asymmetry coefficient.

For ^{10}B two terms, corresponding to the transition into the ground, a_0, and first excited, a_1, states, contribute to the asymmetry a: $a=a_1+\epsilon a_0$, where ϵ amounts to 0.07 according to calculated data.

The average value of the asymmetry coefficient in the fission of ^{235}U is equal to $(0.84 \pm 0.06)\times 10^{-4}$. This is about a factor of two smaller than the value obtained in Ref. 4. The reasons for the discrepancy are still unclear.

The contribution of the β particles from the decay of the fission fragments, remaining in the thick substrate, amounts to a few percent of the detector current and the lack of asymmetry, associated with them, was verified in a special experiment at an elevated pressure for which the fragments and α particles were not recorded by the detectors. In one series of measurements with a UF_4 target pick-up occurred in the high-voltage power supply of the chamber, given a false effect. Measurements for different directions of the guiding field completely eliminate this effect.

The pressure operating point in the chamber in the experiments with ^{235}U fission was chosen in terms of the disappearance of time coincidences in the counter actuations when operating in the pulsed mode. Table II lists the results of the measurement of the dependence of the magnitude of the P-odd effect on the pressure in the chamber.

Measurements were made with the guiding field rotated by 90° with respect to the defined particle emission directions. In the $^6Li(n,t)^4He$ reaction a left-right asymmetry

TABLE II

	Pressure of mixture, abs. atm.		
	0.55	0.45	0.30
Ratio of counting rate of heavy fragments to light fragment counting rate, %	8	20	90
P-odd asymmetry, $\alpha^+ \times 10^{+5}$	6.6 ±0.8	4.7 ±1.7	3.0 ±1.0
P-odd asymmetry in depolarized beam $\alpha^+ \times 10^{+5}$	−0.5 ±1.5	+0.7 ±2.0	

TABLE III

	Reaction		
	$^6Li(n,t)^4He$	$^6Li(n,t)^4He$ *	$^{10}B(n,\alpha)^7Li$
Right-left asymmetry, guiding field up, $\alpha^+ \times 10^{+5}$	7.1 ±0.3	−1.1 ±0.8	−0.22 ±0.28
Right-left asymmetry, guiding field down, $\alpha^- \times 10^{+5}$	−6.6 ±0.5	—	−0.72 ±0.69
Average asymmetry value $\bar{\alpha} = (\alpha^+ - \alpha^-)/2 \times 10^{+5}$	6.9 ±0.3	−1.1 ±0.8	−0.25 ±0.37
Average value of cosine of angle $p_l(\sigma \cdot p_l)$, $\cos\theta$	0.75	0.75	0.62
Right-left asymmetry coefficient, $B = \frac{\bar{\alpha}}{P\overline{\cos\theta}} \times 10^{+5}$	9.5 ±0.4	−1.5 ±1.1 *	−0.40 ±0.60

*Beam is depolarized.

try is found, corresponding to the correlation

$$w \sim \{1 + b\vec{\sigma}[\mathbf{p}_n, \mathbf{p}_l]\}, \tag{3}$$

where $\mathbf{p}_n$ is the unit vector in the direction of the momentum of the bombarding neutron. The results of measurements with ^{10}B, ^6Li targets are given in Table III. The existence of asymmetry in the reaction in ^6Li is apparently due to interference of the S and p states in the $^6Li + n$ system.

Thus, limits on the value of the P-odd asymmetry of light-fragment emission have been established for the $^{10}B(n,\alpha)^7Li$ and $^6Li(n,t)^4He$ reactions $|a| < 0.05 \times 10^{-5}$ and $|a| < 1 \times 10^{-5}$, respectively (at the 90% confidence level). For the ^{235}U fission reaction by thermal neutrons the existence of P-odd asymmetry, previously found in Ref. 4, is verified. The left-right asymmetry in the $^6Li(n,t)^4He$ reaction limits the accuracy capability of measuring the P-odd asymmetry; however, it can prove useful for analyzing reactions in the $^6Li + n$ system.

In conclusion the authors wish to thank the VVR-M reactor staff, N.S. Tikhomirov for his rapid work in setting up the apparatus, B.M. Ovchinnikov and A.S. Barabash for purifying the gases for the chamber operation mixtures, and B.E. Shtern for valuable comments on the design of the experiment.

[1]V.M. Lobashev, V.A. Nazarenko, L.F. Saenko, L.M. Smotritskiĭ and G.I Kharkevich, Pis'ma Zh. Eksp. Teor. Fiz. **3**, 268 (1966) [JETP Lett. **3**, 173 (1966)].
[2]E.A. Kolomenskiĭ, V.B. Kopeliovich, V.M. Lobashev, V.A. Nazarenko, A.I. Okorokov, A.N. Pirozhkov, L.M. Smotritskiĭ, G.I. Kharkevich and A.F. Shchebetov, Yad. Fiz. **25**, 233 (1977) [Sov. J. Nucl. Phys. **25**, 127 (1977)].
[3]A.I. Egorov, V.M. Lobashev, V.A. Nazarenko, G.D. Porsev and A.P. Serebrov, Yad. Fiz. **19**, 300 (1974) [Sov. J. Nucl. Phys. **19**, 147 (1974)].
[4]G.V. Danilyan, B.D. Vodennikov, V.P. Dronyaev, V.V. Novitskiĭ, V.S. Pavlov and S.P. Borovlev, Yad. Fiz. **27**, 42 (1978) [Sov. J. Nucl. Phys. **27**, 21 (1978)].