Investigation of the angular dependence of the escape of ^{233}U and ^{235}U fission fragments as a result of capture of a polarized thermal neutron

V. A. Vesna [1)], V. A. Knyaz'kov [1)], E. A. Kolomenskiĭ [1)],
V. M. Lobashev [1,2][4], A. N. Pirozhkov [1][4], L. A. Popeko [1][4], L. M. Smotritskiĭ [2][4], S. M. Solov'ev [3][4], and N. A. Titov [2][4]

(Submitted April 22, 1980)
Pis'ma Zh. Eksp. Teor. Fiz. **31**, No. 11, 704–709 (5 June 1980)

The *P*-parity nonconserving asymmetry of the fission of ^{233}U and ^{235}U was measured by using the integral method. The escape asymmetry coefficients of a light fragment are equal to $(3.60 \pm 0.34)\times 10^{-4}$ and $(0.75 \pm 0.12)\times 10^{-4}$, respectively. The violation of spatial parity is accompanied by a *P*-parity-conserving, left-right asymmetry with the coefficients $(-3.24 \pm 0.33)\times 10^{-4}$ and $(1.65 \pm 0.11)\times 10^{-4}$, respectively.

PACS numbers: 25.85.Ec

Borovinkova *et al.*[1] described a device for measuring the escape asymmetry of a heavy charged particle in polarized-thermal neutron capture reactions. The use of an integral method for detecting the reaction products with separation of the light and heavy particles according to the path length in the gas has made it possible to increase the sensitivity of the experiment by more than an order of magnitude. The escape asymmetry of the light (heavy) fragment in the direction of and opposite to the compound-nucleus spin, which is attributable to the violation of spatial parity, i.e., a weak nucleon-nucleon interaction, is of considerable interest. Such asymmetry was initially

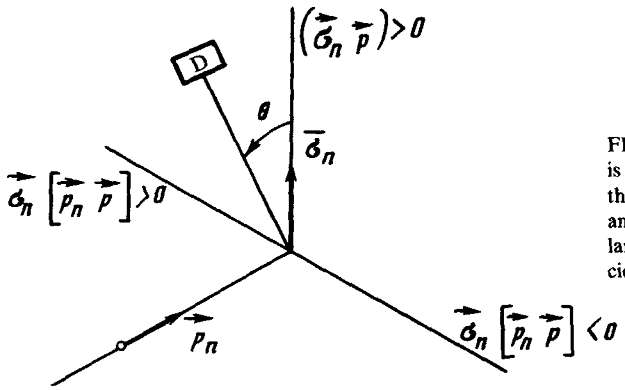

FIG. 1. Geometry of experiments. θ is the angle between the unit vector in the direction of neutron polarization and the detector D in the perpendicular plane to the momentum of the incident neutron.

observed in the fission of heavy ^{233}U, ^{235}U, and ^{239}Pu nuclei by polarized thermal neutrons.[2–4] These processes must be investigated in detail because of the vagueness of the theoretical description of this effect. In this investigation we have measured the probability for the escape of a fragment in the perpendicular plane to the direction of neutron incidence as a function of the angle between the direction of fragment escape and the spin of the captured neutron in the fission of ^{233}U and ^{235}U.

The investigation was performed at the B.P. Konstantinov Institute of Nuclear Physics, using a polarized thermal-neutron beam with an intensity of 6×10^7 neutrons-/sec of the VVR-M reactor.[5] Two multifilamentary proportional counters which recorded only the light fragments[1] in the current mode, were used as detectors. The targets were fabricated by thermal deposition of UF_4 on 100 to 200-μg/cm^2-thick titanium substrates. The thickness of the ^{233}U layer was 150 μg/cm^2 and that of ^{235}U was 500 μg/cm^2. To equalize the fragment spectra on both sides of the target, we covered the UF_4 surface with a second titanium foil. The neutron spin was flipped adiabatically with respect to the guiding magnetic field in a crossed, high-frequency magnetic field and in a nonuniform constant magnetic field.[5] When the high-frequency magnetic field was turned off, the neutron retained its polarization direction along the guiding field and the on-off cycle was equal to 3.6 sec. The polarization direction of the neutron beam with respect to the detectors was reversed periodically (about every 24 hours) by reversing the current in the Helmholtz coils that produced the guiding magnetic field for the neutrons in the target. The sought-for effect, therefore, changed its sign, all things being equal. The asymmetry coefficient was calculated as one-half the difference in the value obtained for opposite directions of the guiding field. The use of two different methods for changing the spin direction enabled us to obtain a result that was corrected for instrumental asymmetry four times faster than in the case of measurements using a polarized and a depolarized beam. In contrast to Ref. 1, we measured the asymmetry coefficient separately by using two detectors that were symmetrically placed on both sides of the target. This made it possible for us to further monitor the instrumental asymmetry.

Figure 1 shows the geometry of the experiments. We show one of the two, sym-

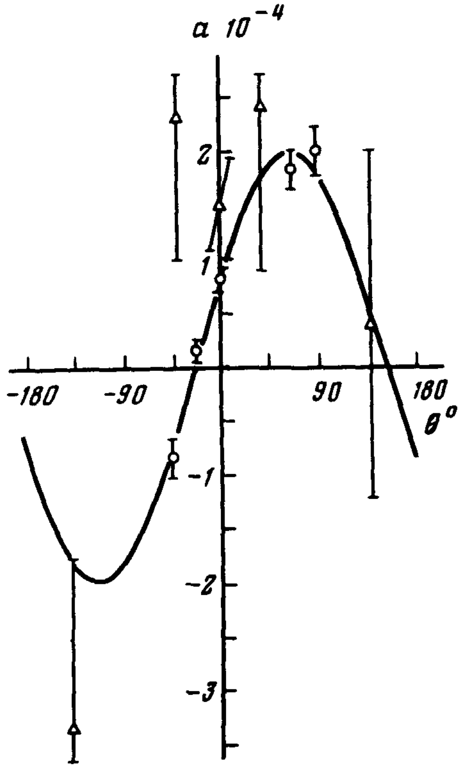

FIG. 2. Escape asymmetry of the light fragment in the ^{235}U fission: ♀—data of our experiment ⧍—data of Ref. 3.

metrically positioned detectors, which corresponds to the asymmetry signs given below (a plus sign denotes preferential passage of a light fragment into the dectector). Figures 2 and 3 show the asymmetry coefficients for the escape of a light fragment as a result of fission of ^{233}U and ^{235}U: $a = (N_+ - N_-)/(N_+ + N_-)$, where N_+ and N_- are the number of light fragments that go into the detector and in the opposite direction, respectively. The asymmetry coefficients, which were averaged over both detectors, were corrected for the degree of the beam polarization (97%) and for the detector-length factor (0.81). In the calculation the asymmetry coefficients were assumed to be constant for all the terms of the light group of fragments. In addition to the *P*-parity violating asymmetry ($\theta = 0$ and 180°), we observed a left-right asymmetry ($\theta = \pm 90°$) corresponding to the correlation between the neutron spin and the vector of the reaction plane of the type $\boldsymbol{\sigma}_n [\mathbf{P}_n, \mathbf{P}]$, where $\boldsymbol{\sigma}_n$, $\mathbf{P}_n$, and $\mathbf{P}$ are unit vectors in the direction of the neutron spin and the momenta of the neutron and light fragment, respectively. In this notation the most probable mechanism for the occurrence of left-right asymmetry is the interference of the *s* and *p* states in the thermal neutron capture reaction, which is analogous to that observed earlier in the $^6Li(n,t)^4He$ reaction.[1] Addition of two independent angular distributions of the form $W(\theta) \sim 1 + a\cos(\theta + \theta_0)$ gives the same kind of total asymmetry which is rotated by an angle equal to the arctangent of the ratio of their coefficients. As for the pure left-right asymmetry, the rotation amounts to $-24.1 \pm 2.2°$ (^{235}U fission) and $+48. \pm 4°$ (^{233}U fission). The error in the

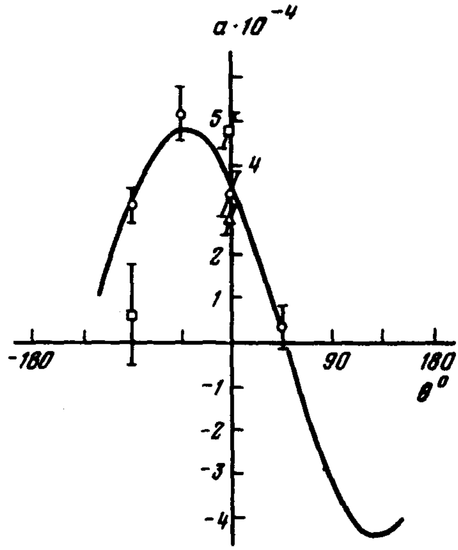

FIG. 3. Escape asymmetry of the light fragment in the ^{233}U fission: ⌽—data of our experiment ⍋—data of Ref. 4, ⌷—data of Ref. 6.

adjustment of the guiding magnetic field, i.e., the direction of neutron polarization, relative to axis of detector I–target-detector II is less than 3°. Another possible source of discrepancy between the geometrical and actual detector axes is the displacement of the center of mass of the "glowing region" of the target relative to its geometrical center. Since the titanium substrates are "transparent" to the fragments, such a displacement should be in the opposite direction for both detectors. In our measurements the asymmetry rotation angles for the opposite detectors are within the experimental error limits $\Delta\theta_0 = 2.2 \pm 4.7°$ (^{235}U fission) and $\Delta\theta_0 = 14 \pm 7.5°$ (^{233}U fission). The obtained results are consistent with the constraint on the coefficient of left-right asymmetry in the ^{235}U fission: $|a_{R-L}| < 3 \times 10^{-4}$ (90% confidence level). The reasons for the discrepancy between Ref. 3 and Ref. 6 are not clear.

Thus, it has been established that *P*-odd asymmetry in the ^{235}U and ^{233}U fission with the coefficients $(0.75 \pm 0.12) \times 10^{-4}$ [4] and $(3.60 \pm 0.34) \times 10^{-4}$ is accompanied by a *P*-odd, left-right asymmetry with the coefficients $(1.65 \pm 0.12) \times 10^{-4}$ and $(-3.24 \pm 0.33) \times 10^{-4}$, respectively.

Extrapolation of the contribution of *P*-wave neutron capture at energies of 0.1–30 keV [7] to the region of thermal energies shows that the left-right asymmetry corresponds to almost the maximum possible interference of the *s* and *p* amplitudes, if the highly unlikely case of the entrance of *p* resonance into the thermal region is disregarded for both nuclei. If such interpretation of the observed *P* odd asymmetry coincides with reality, then we can realize in the nuclear fission process the conditions for which the mixing of the *s* and *p* states due to capture of a thermal neutron can be preserved at the stage of a hot compound nucleus to the stage of a pear-shaped deformation and can determine the fragment emission asymmetry. Analogously, an addition of the states of opposite parity at the stage of the hot compound nucleus, which are retained during its cooling, determine the P-odd asymmetry of the fragment emission. Thus, there are reasons to believe that parity nonconservation in the fission process, which is basically identical to the escape asymmetry of γ-ray quanta in the capture of polarized neutrons, is determined by the dynamic enhancement effect, consistent with the hypothesis advanced in Refs. 8 and 9 and inconsistent with the explanations proposed in Refs. 10 and 11.

In conclusion, the authors thank the personnel of the VVR-M reactor and the coworkers in the information and computer center of the neutron research laboratory, and also Yu. V. Ryabov for a discussion of the contribution of the p wave to the ^{235}U fission.

[1)]B. P Konstantinov Leningrad Institute of Nuclar Physics, USSR Academy of Sciences.
[2)]Institute of Nuclear Research, USSR Academy of Sciences.
[3)]V. G. Khlopin Radium Institute.
[4)]The result of Ref. 1 for ^{235}U [$a = (0.84 \pm 0.06) \times 10^{-4}$] is in good agreement with the measurement data.

[1]N. V. Borovikova, V. A. Vesna, A. I. Egorov, V. A. Knyaz'kov, E. A. Kolomenskiĭ, V. M. Lobashev, A. N. Pirozhkov, L. A. Popeko, L. M. Smotritskiĭ, N. A. Titov, and A. I. Shabliĭ, Pis'ma Zh. Eksp. Teor. Fiz. **30**, 527 (1979) [JETP Lett. **30**, 495 (1979)].
[2]G. V. Danilyan, V. V. Novitskiĭ, V. S. Pavlov, S. P. Borovlev, B. D. Vodennikov, and V. P. Dronyaev, Pis'ma Zh. Eksp. Teor. Fiz. **24**, 380 (1976) [JETP Lett. **24**, 344 (1976)].
[3]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)].
[4]B. D. Vodennikov, G. V. Danilyan, V. P. Dronyaev, V. V. Novitskiĭ, V. S. Pavlov, and S. P. Borovlev, Pis'ma Zh. Eksp. Teor. Fiz. **27**, 68 (1978) [JETP Lett. **27**, 62 (1978)].
[5]E. A. Kolomenskiĭ, V. B. Kopeliovich, V. M. Lobashev, V. A. Nazarenko, A. I. Okorokov, A. N. Pirozhkov, L. M. Smotritskiĭ, and A. F. Shchebetov, Yad. Fiz. **25**, 233 (1977) [Sov. J. Nucl. Phys. **25**, 127 (1977)].
[6]A. K. Petukhov, G. A. Petrov, S. I. Stepanov, D. V. Nikolaev, T. K. Zvezdkina, V. I. Petrova, and V. A. Tyukavin, Pis'ma Zh. Eksp. Teor. Fiz. **30**, 470 (1979) [JETP Lett. **30**, 439 (1979)].
[7]Yu. V. Ryabov and Yu. I. Fenin, Yad. Fiz. **13**, 1039 (1971) [Sov. J. Nucl. Phys. **13**, 596 (1971)].
[8]O. P. Sushkov and V. V. Flambaum, Preprint IYaF Sib. Branch USSR Acad. Sci., No. 80-18, 1980.
[9]E. S. Rzhevskiĭ, Preprint ITEF-154, 1979.
[10]N. S. Rabotnov Yad. Fiz. **26**, 1302 (1977) [Sov. J. Nucl. Phys. **26**, 687 (1977)].
[11]O. P. Sushkov and V. V. Flambaum, Yad. Fiz. **31**, 55 (1980) [Sov. J. Nucl. Phys. **31**, 28 (1980).