Asymmetry in the separation of fragments of the fission of U^{235} and Pu^{239} by slow polarized neutrons

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The spatial parity-violating and parity-conserving asymmetry has been investigated in the separation of fragments of the fission of U^{235} and Pu^{239} by slow polarized neutrons. The average values of the asymmetry coefficients and the experimental distributions of the coefficients as a function of the mass and total kinetic energy intervals of the fission fragments have been obtained.

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The violation of spatial parity during the fission of heavy unpolarized nuclei by slow polarized neutrons was experimentally observed for the first time in Refs. 1–3. The experimental effect involves the fact that the escape probabilities of a group of "light" ("heavy") fragments along and opposite the polarization direction of the neutron beam are different and the magnitude of the asymmetry amounts to $\sim 10^{-4}$.

Subsequently the violation of spatial parity during fission was investigated under other experimental conditions and using other methods of measurement and data analysis in Refs. 4–7. In Ref. 7 a left-right escape asymmetry of the fragments of the fission of U^{235} and U^{233} by polarized neutrons was observed that is *P*-parity conserving and has the form[3]:

$$W(\theta) = 1 + a_{\perp}\vec{\sigma}_n[\mathbf{p}_n \mathbf{p}],$$

where $\boldsymbol{\sigma}_n, \mathbf{p}_n, \mathbf{p}$ are the unit vectors in the neutron polarization and momentum directions and the direction of the momentum of the fragments, respectively.

The goal of our work was to measure the asymmetry of the separation of the fragments of the fission of Pu^{239} by polarized neutrons using the method of mass distributions, developed for studying the dependence of the asymmetry coefficient on the characteristics of the exit channel of the reaction and used by us earlier in Ref. 5. In this paper, however, it was not the goal to obtain such information; therefore, we had not attempted to achieve the maximum energy resolution.

A neutron beam with an intensity of 6×10^7 neutrons/cm^2·sec and a polarization of $\geqslant 95\%$ was obtained by means of a polarizing neutron guide ($\lambda_{\max} = 1.5$ Å) in the horizontal channel of the VVRM reactor. The neutron polarization direction was reversed (once every 2–3 sec) by means of a combination of adiabatic and nonadiabatic reversible magnetic fields.

Two semiconductor detectors with a diameter of ~ 40 mm (source diameter is

~30 mm, distance to detectors is ~12 mm) were used to detect coincident paired fission fragments from the thin target (uranium and plutonium fluorides).

The average detection direction of the fission fragments was chosen either parallel or perpendicular to the polarization direction of the neutrons depending on whether *P*-parity nonconserving ($a_{\parallel}$) or conserving ($a_{\perp}$) asymmetry was being measured.

Besides the periodic change in polarization direction, the direction of the guiding magnetic field in the vincinity of the target and detectors was changed every 15–18 hours; this made it possible, through a joint analysis of the results, to monitor possible instrumental asymmetry of the apparatus simultaneously and to reduce its influence on the measured quantities.[5]

The electronic part of the setup in line with an Elektronika-100 computer provided for the amplification, shaping, selection, recording and sorting of the coincident fission events from the two detectors. The energy spectra of the coincident fission fragments were recorded in the experiment. The ultimate results of the measurements and data analysis were the distributions of the escape asymmetry coefficient of the "light" ("heavy") fission fragments relative to the polarization direction for different mass and total kinetic energy intervals[5] (Fig. 1 and Fig. 2).

The mass calculations were made either on the equipment by means of a specially developed block of relations or through a computer analysis of the two-dimensional matrix of events ($E_1 \times E_2$).

The second method is more informative, permiting easy monitoring of the energy resolution of the detectors, calibration and discrimination of events that are distorted by fragment energy absorption effects in the target and "dead layer" of the semiconductor detectors.

For the existing experimental conditions the result for U^{235} at the standard deviation level was obtained after a day of measurement time. The difficulty of the experiment, especially in the Pu^{239} case, lay in the fact that the energy resolution of the detectors started to deteriorate markedly after a very short measurement time because of radiation damage to them.

The values we obtained for the average asymmetry coefficients of the light fragment groups of the U^{235} and Pu^{239} fission, corrected for the finite detection solid angle for the fragments and the degree of neutron polarization, are summarized in Table I, where the data of other authors are given for comparison.

It is seen from an analysis of the data that all the results agree satisfactorily with one another in terms of order of magnitude and sign despite differences in the measurement methods and conditions. However, our numerical values are systematically larger than the results of the other authors; this may be due to the more clearcut mass separation of the fragments in our measurement method or to the presence of a dependence of the average asymmetry coefficients on the neutron wavelength. The possible systematic errors arising from the introduction of corrections for the finite solid angle for the detection of the fragments and the degree of polarization apparently do not exceed 10–15% and cannot be the cause of the discrepancies.

Especially large discrepancies are observed in the results for the left-right asym-

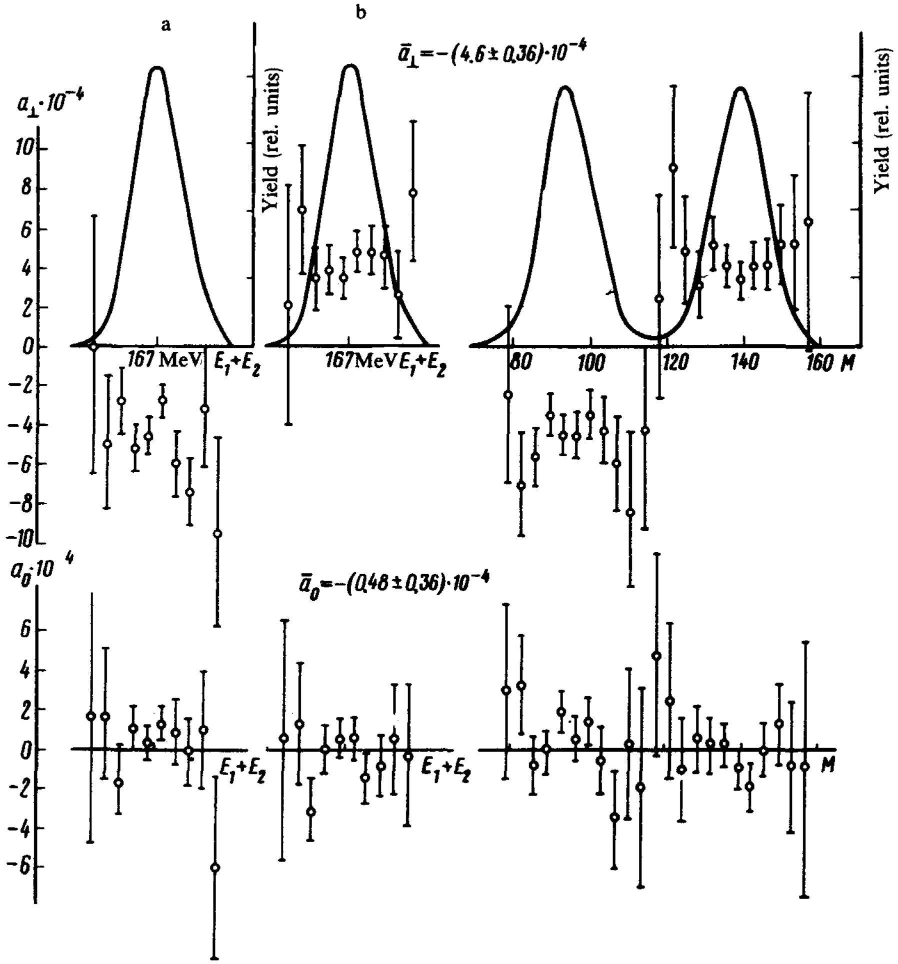

FIG. 1. Top: experimental distributions of left-right fragment escape asymmetry coefficient of U^{235} fission (experimental points) and the experimental mass and total kinetic energy yields of fragments (solid curves). Bottom: experimental distributions of instrument asymmetry coefficient.

metry coefficient for U^{235} fission. The discrepancy decreases appreciably when the neutron momentum dependence [λ_{avg}(Ref. 7)/$\lambda_{\text{avg}} \approx 1.5$] of the left-right asymmetry coefficient is taken into consideration (s- and p-interference during capture). The left-right escape asymmetry of the Pu^{239} fission fragments turned out to be relatively small and it therefore cannot cause any significant distortion of the magnitude of the P-parity-nonconserving asymmetry of the fission fragments.

The experimental distributions of the asymmetry coefficients for the cases of U^{235} and Pu^{239} fission are given in Fig. 1 and Fig. 2 together with the mass and kinetic energy distributions. The total kinetic energy distributions are given for the two directions of detecting the light group of fragments: along the neutron polarization direc-

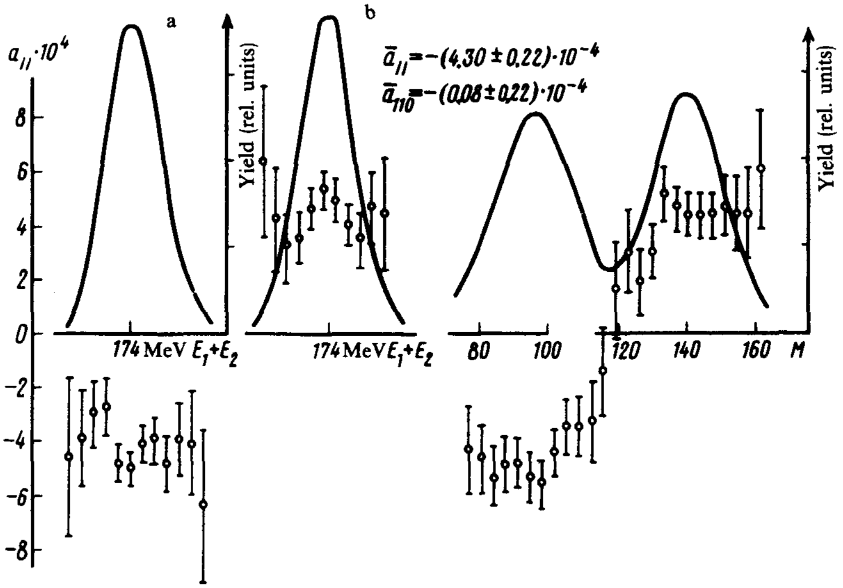

FIG. 2. Experimental distributions of the *P*-parity nonconserving asymmetry coefficient of the escape of Pu^{239} fission fragments (experimental points). Solid line shows experimental mass and total kinetic energy yields of fragments.

TABLE I.

	U^{233}	U^{235}	Pu^{239}	References
$\bar{a}_{\perp} \cdot 10^4$	−(3.24 ± 0.33)	(1.65 ± 0.11)	—	[7]
	−(6.43 ± 0.51)	—	(1.25 ± 0.29)	this paper
$\bar{a}_{\parallel} \cdot 10^4$	(3.6 ± 1.0)	—	—	[1]
	(2.8 ± 0.3)	—	—	[2]
	—	(1.50 ± 0.44)	−(4.8 ± 0.8)	[3]
		—	−(7.8 ± 1.3)	[4]$^{1)}$
	(4.83 ± 0.38)	—	—	[5]
	—	(0.84 ± 0.06)	—	[6]
	(3.60 ± 0.34)	(0.75 ± 0.12)	—	[7]
	(5.28 ± 0.25)	—	−(6.22 ± 0.35)	this paper
	(3.75 ± 0.58)	—	—	[10]$^{1)}$

tion (case "*a*") and opposite to this direction (case "*b*"). The errors shown are statistical; the point spread is somewhat reduced because of the procedure of plotting the histogram in going from the $E_1 \times E_2$ matrix (32×32 channels) to the mass and energy distributions and the procedure of recalibration through the combining of individual measurement series. A comparison of the asymmetry coefficient distributions for different mass intervals clearly reveals the influence of mass resolution. Therefore, on the basis of the distributions we obtained it is still impossible to draw any conclusions about the character of the dependence of the asymmetry coefficient on M and $E_1 + E_2$.

In recent theoretical papers[8,9] an attempt has been made to explain the observed *P*-odd asymmetry effects as the result of a mixing of highly excited states of a compound nucleus with opposite parity. If we follow these researches then no definite dependence of the asymmetry coefficient on the properties of the exit channels of the fission reaction is to be expected.

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[1)] The value given has been recalculated from neutron data.

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