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MASS/ENERGY DEPENDENCE OF THE P-odd ASYMMETRY COEFFICIENT OF THE FRAGMENTS ANGULAR DISTRIBUTION FOR FISSION OF ^{233}U INDUCED BY POLARIZED COLD NEUTRONS: Preprint ITEP 53-98/

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For fission of ^{233}U induced by polarized cold neutrons the dependence of PNC asymmetry coefficient $\alpha_{nf}(M_{lf},TKE)$ on light fragment mass M_{lf} and total kinetic energy TKE was studied. Altogether more than $2*10^{10}$ fission events with high mass / energy resolution have been collected. This corresponds to an increase in statistics compared to previous experiments / 1,2 / by a factor of 20. The preliminary analysis of the PNC asymmetry shows no significant variation of α_{nf} for different masses / energies, whereas the prediction concerning the angular dependence confirmed with a precision unreached up to now.

Исследовалась зависимость коэффициента Р-нечетной асимметрии $\alpha_{nf}(M_{LF},TKE)$ разлета осколков деления ядер ^{233}U поляризованными холодными нейтронами от массы легкого осколка M_{LF} и суммарной кинетической энергии парных осколков, TKE. Было набрано более, чем $2*10^{10}$ событий деления с высоким массово-энергетическим разрешением, что примерно в 20 раз превышает набранную статистику в предыдущих экспериментах / 1, 2 /. Предварительный анализ показал отсутствие заметной зависимости α_{nf} от масс и энергии осколков. Впервые с высокой точностью подтверждена предсказанная теорией угловая зависимость асимметрии.

Fig.- 3, ref. - 12 name.

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Introduction

Parity nonconservation (PNC) in fission induced by polarized slow neutrons has been discovered many years ago /3/. It became apparent as a correlation between the direction of emission of light (or heavy) fission fragments, $\mathbf{P}_f$, and the direction of neutron spin, $\mathbf{S}_n$:

$$W(\theta) = \text{Const.}\ (1 + \alpha_{nf} P_n \mathbf{S}_n \mathbf{P}_f) = \text{Const.}\ [1 + \alpha_{nf} P_n \cos(\theta)], \qquad (1)$$

where θ is the angle between the neutron spin direction and momentum of light fragment and P_n is the degree of neutron beam polarization. The absolute magnitude of asymmetry coefficient α_{nf} is typically 10^{-4}- 10^{-3} as for asymmetry of neutron capture gamma-rays /4/. The size of the observed P-odd effects in nuclear reactions passed through compaund states is defined mainly by the efficiency of the mechanism for the mixing of opposite parity states by weak internucleon potential /5/.

According to Bohr concept /6/, the angular distribution of fragments is governed by the properties of the involved transition states at the saddlepoint of a nucleus undergoing fission. To cover P-odd asymmetry of the fragments angular distribution which is different for light and heavy fragments (asymmetry coefficients have opposite signs), the concept has been slightly modified.

All calculations of the potential energy surface of a deforming nucleus, which take shell and pairing effects into account, predict that outer saddle of double-humped fission barrier is rotationally symmetric, but not reflection symmetric, i.e. is pear-shaped. Hence the transition states at second saddlepoint are doublets of closely spaced states with opposite parity, while the spin projection K remains the good quantum number. A phenomenological model /7/ accredits the observed P-odd asymmetry to the interference of transition amplitudes from doublet-states to the same final state. The main prediction of this model is the proportionality of asymmetry coefficient to the K value in the simplest case when open one transition state only.

On the other hand the detail calculations of Brosa et al. /8/ of the potential energy surface show that there are a few valleys (Brosa-modes) through which nucleus passes from saddle to scission and that the mass/energy distributions of fragments for different valleys are not the same. From the theoretical point of view /9/ the link between K -states and the different valleys is a smoothly varying function. In contrary, experiment /10/ displaying very strong dependence of the angular distributions of fragments on mass/energy intervales. It should be mentioned that there is the result /11/ which contradicts to /10/. In any case the investigation of the dependence PNC asymmetry on mass/energy of the fragments seems to be very important.

Experimental Setup and Methods

The measurements were performed at the ILL, France, at the cold polarized neutron beam PF1, where the neutron polarization was $P_n = (95 \pm 1)$ %. Behind the polarizer a fourfold back-to-back ionisation chamber was placed. In each of the four sections a target of 5 μg ^{233}U on a thin carbon backing (25 μg/cm ^{2}) covered a circular aperture in the center of the of the common cathode. The longitudinally polarized neutron beam traverses the chamber along the symmetry axis normal to the cathode and anode planes. Since the three pulsehights delivered by the electronics for each single fission event (*pha* from anode *a*, *phb* from the anode *b* and *phc* from the cathode *c*) are to good approximation proportional to the kinetic energies of fission fragments being stopped in the gas volume, the mass ratio of complementary fragments may be inferred. This yielded a mass resolution of better than 1 amu in the cold region, rapidly deteriorating as soon as neutron evaporation sets in. The excelent resolving power of the chamber is evident from Fig.1, a scatterplot of the kinetic energies of two fragments, where clearly masslines can be seen (the final energy calibration is not yet available, so the kinetic energies indicated in the scatterplot are still preliminary). The standard spin-flip-technique was used to overcome all kind of electronic and instrumental asymmetries (like long-time drifts and backing effects). Every second the direction of the spin of the incoming neutrons was reversed by a current sheet spin flipper. Therefore two scatterplots of this kind are obtained, one for positive helicity of incoming neutros and second for negative helicity. With this two sets of data the experimental asymmetry for different mass- and energy regions can be calculated as :

$$\alpha^{exp} = (N_1 - N_2) / (N_1 + N_2), \tag{2}$$

where N_1, N_2 are the number of light fragments in correspondent mass- and energy regions for positive and negative helicity of neutrons, respectively.

Results and Discussion

Global values :

\# The global asymmetry value (averaged over all masses and energies) was found to be :

$$\alpha_{nf} = (4.00 \pm 0.13).\ 10^{-4}$$

in good agreement with literture / 12/.

\# The values for the two possible directions of the guiding magnetic field are :

$$\alpha_{nf}(\text{field}+) = (4.24 \pm 0.24).\ 10^{-4} \quad \text{and} \quad \alpha_{nf}(\text{field}-) = (3.88 \pm 0.24).\ 10^{-4}.$$

Since reversing the guiding field also reverses the spin of neutrons, the overlap of these two values within statistical accuracy demonstrates the absence of any false asymmetry.

\# The test measurement with an unpolarized (depolarized) neutron beam yielded :

$$\alpha_{nf}(\text{unpol.}) = (0.27 \pm 0.25).\ 10^{-4}$$

which is compatible with zero, as expected.

Angular dependence :

\# The angle θ between the direction of emission of the fragments and the chamber axis (normal to the cathode and anode plane) can be determined by the normalized cathode pulsehight $pcn = phc / (pha + phb)$ with pcn is proportional to cos θ in the following way : since the cathode is not electrically shielded by a Frish-grid, the signal generated by drifting charges lasts until they reach the Frish-grid of the anode. So, the closer to the cathode they are formed, the longer the electrons drift and the higher is the cathode signal. Since the cathode signal also depends on fragments masses and total kinetic energies, it has to be divided by the anode signals to receive the angle θ. In the present experimental setup with longitudinally polarized beam, θ is also the angle relevant for PNC studies, viz. the angle between fragment momentum and neutron spin. For 16 angular range between $\cos(\theta)=1$ and $\cos(\theta)\approx 0$ the asymmetry values measured are plotted in Fig. 2 (data points) together with a least-square fit (line). A difficulty here is that for angles approaching $\theta = 90^0$ no data can be taken since the target holder (a thin Al frame) is screening this angular region. But, nevertheless, the data are in excellent agreement with the expected correlation (1) for the PNC asymmetry.

Mass / energy dependence :

In Fig. 3 the mass- and TKE-dependence of α_{nf} are plotted. In the regions with a sizable yield they exhibit no significant deviation from constant value. The slightly lower values for smaller masses may be due to scattered events (where one of both fragments has lost some part of its energy due to inelastic scattering either in the target-backing or with counting gas nuclei and thus may be identified to have the "wrong" mass) while, when going to more symmetrical masses, the overlap with the heavy fragment masses (where the α_{nf}- values have the opposite sign) comes into play. For the analysis of the experiment in terms of Brosa-modes (Standard I and Standard II) the scatterplots of correlated fragment energies have been deconvoluted into the contributions from the two modes. This was accomplished by fitting two two-dimensional Gaussians to the data. This fit reproduces the experimental mass- and energy-distributions quite well : the Standard II amounts to about 75 % of the total yield and Standard I - 25 %. According to this fit the asymmetry - values for the Brosa - modes have been found to be :

$$\alpha_{nf}(\mathrm{St.I}) = (4.14 \pm 0.27).\ 10^{-4} \quad \text{and} \quad \alpha_{nf}(\mathrm{St.II}) = (3.96 \pm 0.15).\ 10^{-4}.$$

Hence,within the statistical accuracy of about 6 % per mode reached in the present experiment, there is no evidence for the PNC asymmetries to differ in the two standard Brosa modes.

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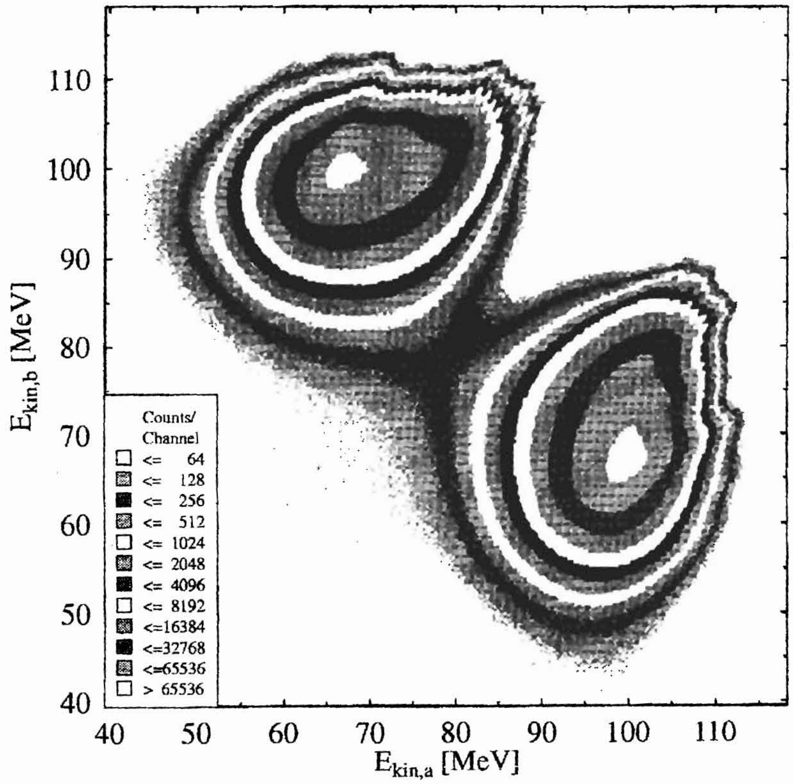

Fig. 1. Scatterplot of kinetic energies ; fragment masses may be inferred from the ratio of kinetic energies. The two "humps" indicate the asymmetric mass-distribution of ^{233}U (n,f). The structure at the highest total kinetic energy indicates resolved fragment mass ratios, so-called ***masslines*** , which demonstrate the excellent resolving power of the ionisation chamber.

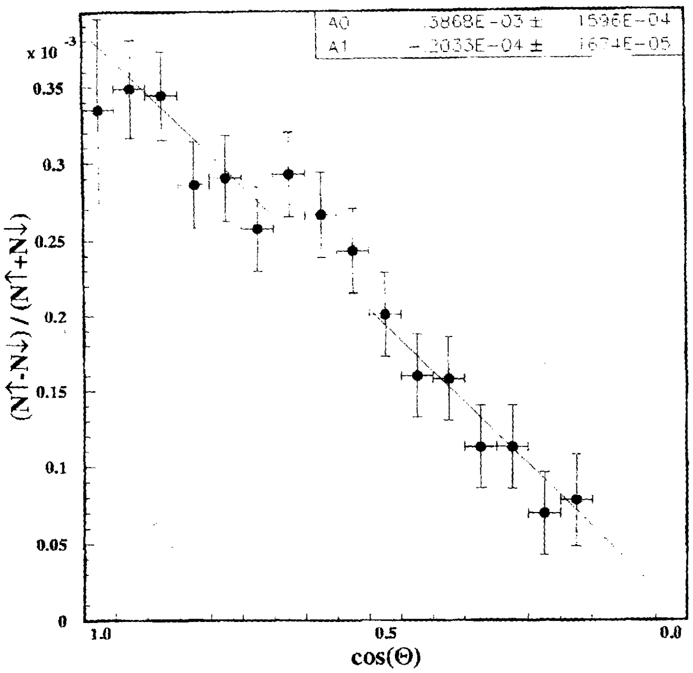

Fig. 2. The measured raw asymmetry $(N_1 - N_2)/(N_1 + N_2)$ of the light fission fragments as a function of $\cos\theta$ confirms the theoretical predictions concerning the shape of PNC asymmetry.

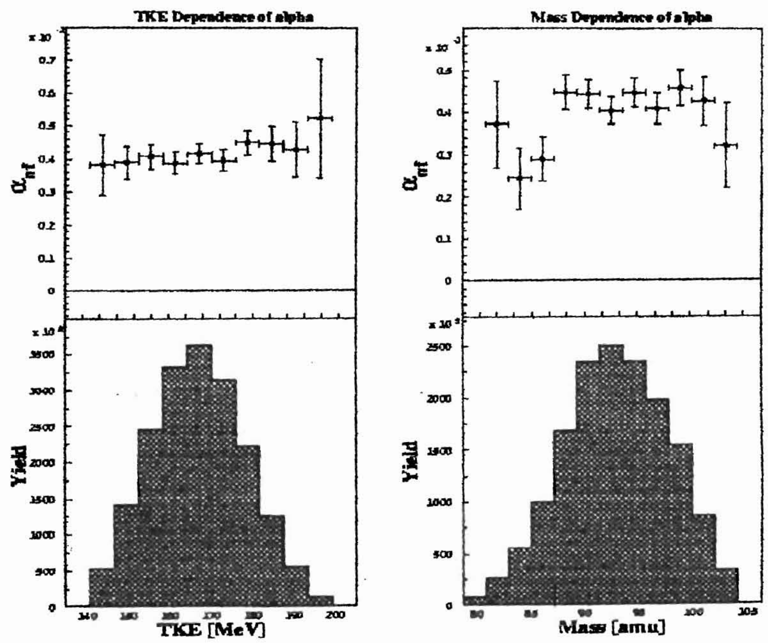

Fig. 3. Dependence of α_{nf} on total kinetic energy TKE (left) and on light fragment mass M_{LF} (right).

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