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Interference Effect in Angular Distribution of Outgoing Particles in Ternary Fission Induced by Cold Polarized Neutrons.

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INTERFERENCE EFFECT IN ANGULAR DISTRIBUTIONS OF OUTGOING PARTICLES IN TERNARY FISSION INDUCED BY POLARIZED COLD NEUTRONS. Preprint ITEP 2-99/

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Unexpectedly large left-right asymmetry of the long range α - particles emission in ternary fission of ^{233}U relative to the plane formed by vectors of neutron spin and light fragment momentum was observed in the experiment performed on the polarized cold neutron beam of ILL HFR. The asymmetry coefficient occur to be equal to $(- 3.5 \pm 0.1) * 10^{-3}$.

На пучке поляризованных холодных нейтронов высокопоточного реактора Института Лауэ-Ланжевена исследовался интерференционный эффект в угловых распределениях продуктов деления в тройном делении ядер ^{233}U. В результате измерений обнаружена неожиданно большая лево - правая асимметрия испускания длиннопробежных α - частиц тройного деления ядер ^{233}U относительно плоскости, определяемой векторами спина нейтрона и импульса легкого осколка. Коэффициент асимметрии оказался равным $(- 3,5 \pm 0,1) * 10^{-3}$.

Fig. – 1, ref. – 4 name.

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The violation of Time Reversal Invariance in some hypotetic interaction follows from the observed CP violated asymmetry in K^0 meson decay in the assumption of the validity of CPT theorem. During more than 30 years many unsuccessful attempts were performed to find some indication on violation TRI in any nuclear processes or reactions. In many of them the T-odd angular correlation was searched. The simplest correlation, for example, in radiative capture of polarized thermal neutrons /1/ is :

$$W = \text{Const.} * (1 + D * \mathbf{I} * [\mathbf{K}_1 \times \mathbf{K}_2]) , \quad (1)$$

where D - correlation coefficient, **I** - the unit vector in the direction of the polarization of nuclei, $\mathbf{K}_1$ and $\mathbf{K}_2$ are the unit vectors in the directions of emission of two gamma's from cascade decay of exited nucleus. The first transition of the cascade should has mixed multipolarity and if TRI is violated then phase between two multipoles must be differ from 0 or π.

The same kind correlation has been searched for in polarized neutron decay /2/ :

$$W = \text{Const.} * (1 + D * \mathbf{S} *[\mathbf{P}_e \times \mathbf{P}_\nu]), \quad (2)$$

here **S** is the unit vector in the neutron polarization direction, $\mathbf{P}_e$ and $\mathbf{P}_\nu$ are the unit vectors in the direction of electron and neutrino emisions, correspondingly.

Such "T-odd" correlations are forbiden only in the first order approximation of perturbation theory and thus in all cases there is some probability to find such correlation, which may arise due to interactions in the final state even when TRI does not violated. But never such effect has been observed.

We decided to search for such correlation in ternary fission induced by polarized slow neutrons :

$$W = \text{Const.} * (1 + D*\mathbf{S}*[P_f \times \mathbf{P}_\alpha]) = \text{Const.} (1 + D*B), \quad (3)$$

where $\mathbf{P}_\alpha$ and $\mathbf{P}_f$ are the unit vectors in the directions of α-particle and light fragment momenta respectively, and

$$B = \mathbf{S} * [\mathbf{P}_f \times \mathbf{P}_\alpha] . \quad (4)$$

The proposal of such experiment has been published many years ago /3/ .

The schematic draft of the detectors layout for TRI experiment is shown on the Fig.1.

Longitudinaly polarized cold neutrons ($\Phi_{pol} = 6 \times 10^8$ n/(cm^2 . s) ; P = 95%) hits the thin ^{233}U target (0.1 mg/cm^2) evaporated onto a titanium foil with diameter 80 mm and thickness 0.12 mg/cm^2 situated along the neutron beam. Complementary fission fragments detected by two multiwire proportional counters (MWPC) , placed at right angles to the beam in a horizontal plane at the equal distance from target ; the ternary α-particles were detected by two arrays of PIN-diodes in the up and down direction respective to central horizontal plane.

In the expression (3) $\mathbf{P}_f$ is the momentum of the light fragment (4). To distinguish between light and heavy fragments the "time-of-flight difference methods" was used. The coincidences of light fragment pulse from left or right MWPC's with pulse of "up" or "down" α-particle detectors are counted separately. Of course, the sign of the function B depends on mode of coincidence. Asymmetry has been defined by measurements the appropriate counts rates for two opposite directions of neutron polarization :

$$b_i = (N_i' - N_i'') / (N_i' + N_i''), \quad (5)$$

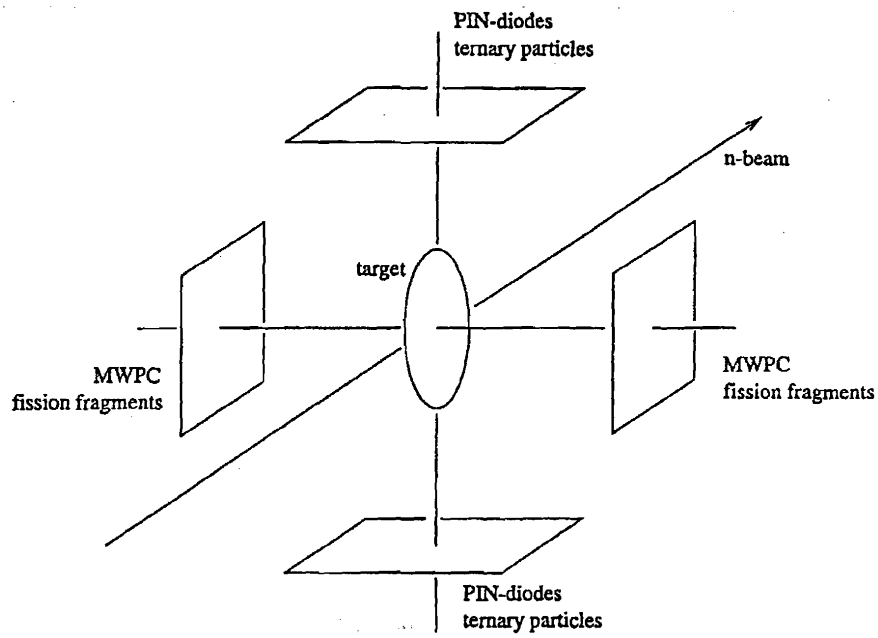

Fig 1. Schematic view of detector setup.

where N_i'- the count rates of i-th mode of coincidence at positive helicity of the neutrons, N_i'' - the same at negative helicity. The polarization direction of the neutron beam was reversed every second using well known spin flip technique without changing other beam parameters. The symmetry of the geometry of detectors system provide us to measure four combinations of coincidence and hence four independent values of coefficient D :

Table 1. Signs of function B for different mode of light fragment-α-particle coincidence

i	direction of light frament	direction of α-particle	sign of B
1.	light fragment is going to the left	α-particle is going up	+
2.	-"- -"- -"- right	-"- -"- up	–
3.	-"- -"- -"- left	-"- -"- down	–
4.	-"- -"- -"- right	-"- -"- down	+

Hence the average value of D will defined by :

$$<D^*> = (D^*_1 - D^*_2 - D^*_3 + D^*_4) / 4 \qquad (6)$$

$$D = D^* / (<B> * <P_n>),$$

where <B> is the average absolute value of B for our geometry of experiment.

MC calculations gave :

$$<B> = 0.71,$$

$<P_n> = 0.95$ is the average value of the neutron beam polarization.

Appart from the correct (according to the Table 1) signs correlations there is an additional possibility to control the contribution of the systematic errors in values of D. Reversing the guide magnetic field without changing other parameters of measurements we can exclude the possible asymmetry effect arised due to the time alteration of the neutron beam intensity.

Of course, the main test experiment is the same measurements on unpolarized (depolarized) beam. In the case of absence of any apparatus asymmetry the coefficient D should be equal zero. The results of measurements are shown in Table 2 .

Table 2. Observed values for asymmetry coefficients D_i^* **in the units of** 10^{-3} for longitudinally polarized and depolarized neutron beam

mode of the coincidence i	guiding field +	guiding field –	depolarized neutron beam (guiding field +)
1	(– 2.40 ± 0.12)	(– 2.44 ± 0.12)	(+ 0.53 ± 0.30)
2	(+ 2.12 ± 0.12)	(+ 2.38 ± 0.12)	(– 0.26 ± 0.30)
3	(+ 2.66 ± 0.12)	(+ 2.44 ± 0.12)	(– 0.40 ± 0.30)
4	(– 2.08 ± 0.12)	(– 2.19 ± 0.12)	(+ 0.20 ± 0.30)

The average value of asymmetry coefficient obtained by combining all eight results of measurements with polarized neutrons occur to be equal:

$$\langle D^{*}\rangle = (-2.34 \pm 0.07)*10^{-3}$$

and according to (6),

$$D = (-3.47 \pm 0.10)*10^{-3}.$$

Thus such kind of interference effect has been observed for the first time. It can be considered as evidence that TRI is violated, but more probably that it is the interference effect in final states interactions (strong or Coulomb). To distinguish between these two possible explanations (TRI violation or final state interaction) it's necessary to evaluate possible effects of the final state interactions. But because the complexity of final states in fission process it is not easy to do. It's obviously that necessary to obtain more detail data such as dependence of the correlation coefficient D on the mass and energy of fragments and the energy of ternary α-particle.

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