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POLAR ALPHA PARTICLE EMISSION FROM ^{235}U THERMAL NEUTRON INDUCED FISSION[1]

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The existence of polar *LRA* particles emitted in the direction of the fission axis in coincidence with a fission fragment was verified. The energy distribution of polar *LRA* particles may be described by a superposition of two Gaussian distributions of most probable energies $E_1 = (22.9 \pm 0.2)$ MeV and $E_2 = (26.7 \pm 0.5)$ MeV and dispersions of $\sigma_1 = (1.55 \pm 0.2)$ MeV and $\sigma_2 = (2.1 \pm 0.5)$ MeV, respectively. The integral cross section of the polar alpha emission was found to be (51.0 ± 3.5) mb.

A particular attention in the heavy nuclei fission study in the last few years has been paid to the ternary fission, namely to the so-called *LRA*-fission. The main group of long range alpha particles in this process is formed by alpha particles emitted perpendicularly to the fission axis (with a full width of about 25 degrees). Recently, after the discovery of a secondary group of alpha particles emitted in the direction of flight of one of the fragments, a number of experimental works concerning this problem has been published [1, 2, 3]. It is easy to demonstrate (see e.g. [4]) that, supposing that these alpha particles are emitted close to the scission point, they cannot be emitted from the „neck region" of the rupturing compound nucleus (in contrast to those of the main group), but from the outer „poles" only. This is the reason, why there were named „polar-alpha particles".

Although relatively few contributions to this problem have been published so far, the experimental results are mutually not in agreement (compare [2] with [3]). It has been decided therefore, to measure the energy spectrum of polar alpha particles from the ternary fission of ^{235}U by thermal neutrons. In these measurements surface barrier semiconductor detectors and the alpha particle-fission fragment coincidence technique have been used and both the alpha particles and the fragments energy spectra have been registered. In this way it has been possible to determine the relative yields of the light and heavy fragments in this process, too.

The fundamental scheme of the experimental set-up is presented in Fig. 1. The vacuum chamber was placed in front of one of the horizontal channels of the *VVR-S* reactor (neutron flux of about 10^8 n/cm^2 sec) and in its center a UO_2 target of an 8 cm^2 area and of circular shape, enriched to 90 % by the ^{235}U isotope, was located. The UO_2 layer,

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of an approximately 200 μg/cm² thickness, was deposited on an aluminium backing of 18 mg/cm² by the electrotechnical exchange method [5]. Two surface barrier semiconductor detectors for the registration of alpha particles and fragments (indexes 1, and 2 in Fig. 1) were placed in the vacuum chamber. The fragment detector (effective surface of 200 mm²) was oriented toward the sensitive layer of target and placed at a distance of 115 mm far away. The alpha particle detector (with a surface of 300 mm² and the barrier depth of 700 μm) was placed on the opposite side of the target at a distance of 55 mm. It was protected against the radiation damage by fission fragments by an Al-foil of a 54 mg/cm² thickness at a distance of 10 mm. The measurements were performed in two geometrical arrangements: a) a polar alpha particles geometry ($\vartheta \doteq 0°$ or 180°), b) a main group alpha particles geometry ($\vartheta \doteq 90°$) as a control measurement.

The pulses from the two detectors passed through a standard chain of preamplifiers and amplifiers to the linear inputs of two amplitude analysers, gated by output pulses of the fast alpha-fragment coincidence with a resolution time of 20 nsec.

The integral numbers of counts on both sides were registered by the scalers $R1$ and $R2$. The energy calibration of the alpha side was accomplished before and after each experimental run with the aid of standard alpha emitters. During the measurements the gain stabilisation was ensured by means of a precision pulse generator. Since the admixture of other ions than alpha particles in the measured energy interval is negligible [3, 7], the use of a $dE/dx + E$ telescope on the alpha side was omitted and it was supposed that all the registered pulses are due to alpha particles.

The measured energy spectrum of alpha particles $N(E_\alpha)$ in the given geometry is the result of a convolution of the angular distribution $Y(\vartheta, E_\alpha)$ and the angular resolution function $F(\vartheta)$, i.e.

$$N(E_\alpha) \sim \int Y(\vartheta, E_\alpha)\, F(\vartheta)\, d\vartheta .$$

The resolution function $F(\vartheta)$ for our geometry was calculated by the Monte-Carlo method, the angular distribution $Y(\vartheta, E_\alpha)$ was supposed to be a Gaussian distribution both for the main group and for the secondary group of polar alpha particles for each energy E_α with the mean values $\langle\vartheta^{(1)}\rangle = 82°$ and $\langle\vartheta^{(2)}\rangle = 0°$ (180°) and an $FWHM$ of 21° and 13° respectively [6]. According to the Monte-Carlo calculations the most probable angle of detection of the polar alpha particles was $\langle\vartheta\rangle = 18°$ (162°), for the main group of alpha particles the most probable angle amounts to $\langle\vartheta\rangle = 88°$.

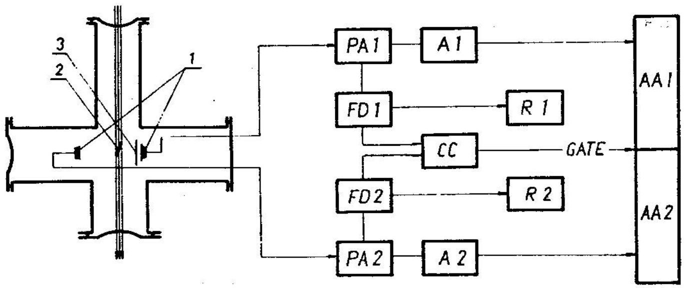

Fig. 1. The block diagram of the experimental set-up. 1 — semiconductor detectors; 2 — uranium target; 3 — aluminium absorber; PA — charged sensitive preamplifiers + + pick-off units; A — linear amplifiers; FD — fast discriminators; CC — coincidence circuit; AA — amplitude analysers; R — scalers (index 1 or 2 of the electronic schemes denotes the alpha or fragment chain, respectively).

The energy spectrum of alpha particles of the main group ($\vartheta \doteq 90°$) is presented in Fig. 2a. The full line is the best Gaussian fit (the correction for the passage of the alpha particles through the Al-absorber are included) to the experimental points with the most probable energy of $E_\alpha = (15.7 \pm 0.3)$ MeV and the dispersion of $\sigma = (3.7 \pm 0.3)$ MeV. These results are in thorough agreement with our previous data and those of other authors [8, 9, 10].

The experimental energy spectrum of polar alpha particles is presented in Fig. 2b. In addition to the true events of the registration of polar alpha particles, the figure contains the background from the alpha-fragment random coincidence too. This background must have the same shape of the spectrum in the Fig. 2a with the integral intensity N depending on the resolution time of the coincidence ($N = 2\tau N_\alpha N_f$, where τ is the resolution time of the coincidence, N_α and N_f are the numbers of counts of the alpha particles and fragments, respectively). The dashed line in Fig. 2b is the Gaussian distribution with the same parameters as in Fig. 2a and the integral intensity $N = 2\tau N_\alpha N_f$. As it may be seen, this curve fits the experimental points sufficiently well. A Gaussian fit of the true distribution of the polar alpha particles (after random coincidences substraction) is presented in Fig. 3. Fig. 3a represents the Gaussian fit of

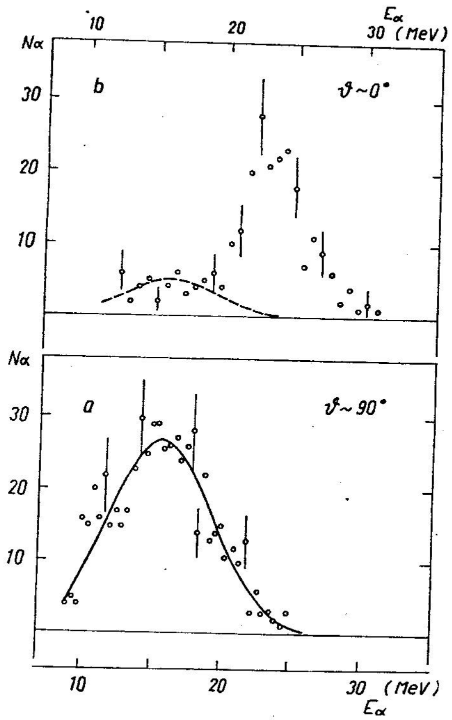

Fig. 2. a) The main group alpha energy spectrum; b) The polar alpha energy spectrum.

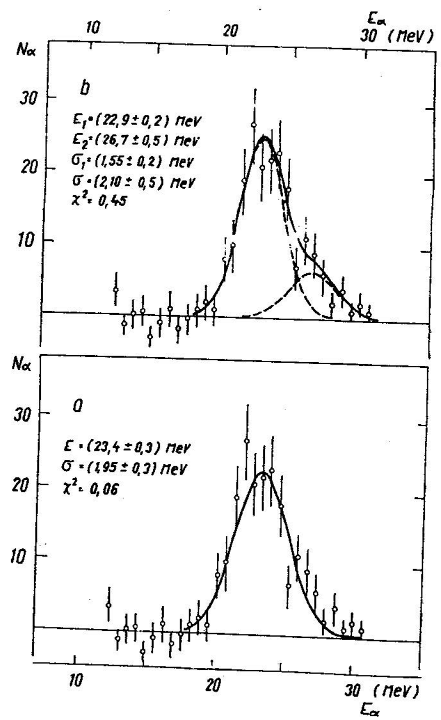

Fig. 3. a) The single Gaussian fit to the experimental points; b) The double Gaussian fit to the experimental points.

the spectrum with the most probable energy of $E_0 = (23.4 \pm 0.3)$ MeV and the dispersion of $\sigma = (1.95 \pm 0.3)$ MeV. The χ^2-test for the goodness of this fit leads to a rather low value of $\chi^2 = 0.06$. In Fig. 3b there is a fit by two Gaussian distributions with the most probable energies $E_1 = (22.9 \pm 0.2)$ MeV and $E_2 = (26.7 \pm 0.5)$ MeV and dispersions of $\sigma_1 = (1.55 \pm 0.2)$ MeV and $\sigma_2 = (2.1 \pm 0.5)$ MeV, respectively. This fit is more plausible, the value of the χ^2-test being 0.45 this time. The intensity ratio of both Gaussian distributions is $I_1/I_2 = 2.7 \pm 1.2$.

The analysis of the amplitude spectra of fragments in polar alpha emission measurements enable us to determine the relative rates of light and heavy fragments at the angle of 162° with regard to the direction of flight of the *LRA* particles. From our measurements we get the values of (76 ± 12) % for the heavy fragments and (24 ± 5) % for the light ones. For reason of low statistics no other parameters of any kind of the fragment energy distribution were established.

Knowing the angular resolution function and supposing the Gaussian shape of the angular distribution of polar alpha particle one has the possibility of the integral cross section of the polar alpha emission determination. From our measurements we obtained the value for the integral cross section of polar alpha emission equal to (51.0 ± 3.5) mb.

The obtained values of parameters of the Gaussian fit (Fig. 3a) may be compared with that of other authors. Comparing our results with these of [3, 6] one can confirm a good agreement of all the data, including the cross section value. The result of the work [2] differs qualitatively from all the results mentioned above. In view of the fact that in [2] a slow coincidence was used ($2\tau = 1$ μsec), the random coincidence background must be much higher than that of the present work and this fact can probably explain the disagreement.

As far as we know, the largest statistical set of polar alpha particles has been accumulated in the present work and this made the separation of the experimental spectrum in two Gaussian distributions possible. The intensities of the distributions are in striking agreement with the relative intensities of light and heavy fragments in polar alpha particle accompanied fission. This fact may be interpreted in such a way that in the direction of flight of the lighter fragment alpha particles of lower kinetic energy are emitted (in Fig. 3b the Gaussian distribution with the index 1). A confirmation of this hypothesis requires, however, further experimental investigations.

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