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ANISOTROPIC FISSION OF U^{238} INDUCED BY 3-Mev NEUTRONS

I. A. BARANOV, A. N. PROTOPOPOV, and V. P. ÉISMONT

Radium Institute, Academy of Sciences, U.S.S.R.

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A double ionization chamber with grids was used to investigate the dependence of the angular anisotropy of U^{238} fission induced by 3-Mev neutrons on the mass ratio of the fission fragment pairs. The anisotropy was found to be constant for mass ratios between 1.25 and 1.65. It was also established that the angular distribution of light and heavy fragments is symmetrical with respect to 90° to within a 3% uncertainty.

In one of the first investigations into the angular distribution of fission fragments[1] a dependence was observed between angular anisotropy and mass asymmetry, in which it was found that the angular anisotropy was greater for asymmetric fission than for symmetric fission. Subsequent research[2-4] showed that such a dependence of angular anisotropy on mass asymmetry persists for cases where the fission of various nuclei is induced by various particles.*

However, these investigations were all conducted under such conditions that fission of nuclei with different excitation energies could occur. Therefore, it was impossible to say whether this dependence was purely accidental and external in nature or an intrinsic characteristic of the fission process itself. The possibility of this being an intrinsic characteristic has been discussed by A. Bohr[5] (the influence of spin and parity of various fission channels) and by Strutinskii[6] (the dependence of the density of the fragment energy levels on the magnitude of their spin).

However, Halpern and Strutinskii[7] showed that this dependence may also be of a purely accidental nature. Actually, since the excitation energies of the fissioning nuclei in all the experiments thus far have been such that nuclear fission could occur either with no preliminary "shedding" of neutrons or with a preliminary "shedding" of one, two, or more neutrons, the temperatures of the nuclei immediately before the division into fragments could be different. Nuclei that have "shed" neutrons will fission in a "cooler" state and therefore more anisotropically than nuclei that have experienced no preliminary neutron "shedding."

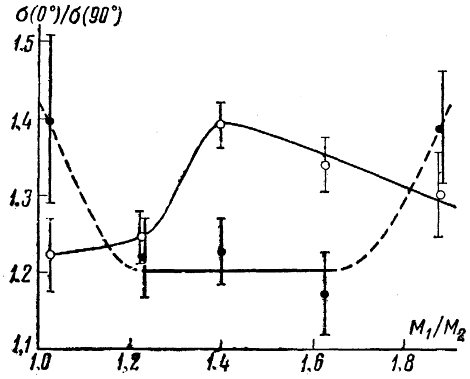

FIG. 1. Dependence of angular anisotropy on fragment mass ratios. ○ – data obtained for 14.9 Mev neutrons; ● – data obtained for 3 Mev neutrons.

Fission asymmetry is also related to the excitation energy of the nucleus. The lower the excitation energy of the nuclei before fission, the greater will be their contribution toward asymmetric fission. Thus it is that nuclei that have "shed" neutrons before fission undergo more asymmetric and anisotropic fission than nuclei that have not first "shed" neutrons.

Experiments in which the excitation of the nucleus is strictly limited should provide an insight into the nature of the dependence between the angular and mass asymmetries. In such a case the excitation must be small enough so that the fission cannot follow the "shedding" of a neutron. These conditions are fulfilled when the experiments involve monoenergetic neutrons with energies up to 5 Mev.

The neutrons used in the present investigation were obtained from the D(d, n)He^3 reaction. These neutrons, which bombarded a uranium target, had an energy of 3 Mev. Because of the slowing down of the deuterons in the thick target and the finite solid angle a neutron energy as low as 0.2 Mev was possible.

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*What is meant here is the fission of heavy nuclei at excitation energies that do not exceed 50 Mev.

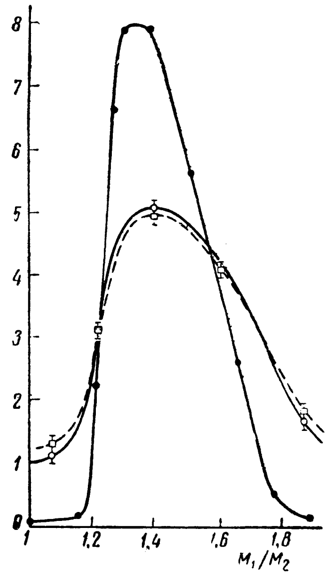

FIG. 2. Relative probability of different fragment mass ratios for U^{238} fission. □ and ○ – present data for 0° and 90° respectively; ● – data obtained by the radiochemical method[9] (fission spectra neutrons).

A double ionization chamber with grids was used to find the angular anisotropy and ratio of the fission fragment masses. The common electrode for the chamber was equipped with a collimator 1 mm thick. The collimator channels, with a diameter of 0.3 mm, were perpendicular to the collimator surface. Because of the low intensity of the neutron flux the target used was rather thick, consisting of natural uranium in the form $(NH_4)_2U_2O_7$ with an overall density of 450 μg/cm^2. The electrostatic spraying method was used to apply the target to a collodion film.[8]

Measurements were made alternately when the chamber was in two positions relative to the direction of the neutron beam. In the first position (0°) the direction of the neutron beam coincided with the axis of the collimator channels, i.e. with the direction in which the fragments were separated. In the second position (90°) the neutron beam entered almost perpendicularly to the axis of the collimator channels. The angular resolution was such that the direction of emission of the fragments did not deviate by more than 28° from the fixed direction of 0° or 90°. In other respects the experimental conditions and technique were the same as described earlier.[4] A total of about 4,000 fissions were recorded in each of the two directions.

To check the reliability of the method under thick target conditions we repeated previous measurements of the dependence of anisotropy on mass asymmetry for 14.9-Mev neutrons in which better energy resolution was had.[4] The results coincided satisfactorily.

Figure 1 shows the measured dependence of angular anisotropy, i.e., the ratios of cross sections $\sigma(0°)/\sigma(90°)$, on the mass ratio of the fragments M_1/M_2 for fission induced by 14.9- and 3-Mev neutrons. One can see that the dependence of anisotropy on the mass ratio for 3-Mev neutrons is of a different nature from the corresponding dependence for 14.9-Mev neutrons. It is essential to note that the measured anisotropy for symmetric and very asymmetric fissions does not reflect the true anisotropy in the corresponding region of the fragment mass ratios. This is evidenced by the fact that the distribution of the mass ratio for fragment pairs (see Fig. 3) for fission at 0° and 90° angles proved to be 1.5 times as wide as the distribution obtained by the radio-chemical method.[9]

The use of a thick target was the main reason for such a wide distribution. A conclusion that can be drawn from a comparison of our mass distribution with the radiochemical one is that in our case the major portion of the symmetric and very asymmetric fissions was composed of fissions that did not in fact belong to the given range of mass ratios. Thus, the major contribution to anisotropy for the mass ratio 1.07 was made by fissions with a mass ratio > 1.07, while the anisotropy for the mass ratio 1.87 was mainly due to fissions with a mass ratio < 1.87. Therefore, when the dependence of angular anisotropy on mass asymmetry was under investigation, only mass ratios between 1.25 and 1.65 could properly be used.

It is nevertheless important that the anisotropy values for mass ratios of 1.07 and 1.87 lie no lower than the anisotropy values for mass ratios between 1.25 and 1.65, as in the case of 14.9-Mev neutrons. What may to some extent account for the somewhat higher position of these points over the others is the fact that the distribution of pulses from fission fragments where the fission is at 0° must be somewhat wider than a distribution recorded at 90°, because of the effect of the motion of the center of mass. The anisotropy is constant for mass ratios between 1.25 and 1.65, which tends to indicate an accidental dependence of anisotropy on asymmetry such as was noted earlier in the case of fission induced by particles of medium energy. In order to determine the degree of anisotropy in the symmetric and very asymmetric regions, measurements with a better resolution are necessary.

Our investigation also resolved the question of a difference in distributions of directions in which light and heavy fragments are emitted. Previous work[2,4,10] on fission by particles with energies not in excess of several tens of Mev has shown that there is no difference between the angular distributions for light and heavy fragments. In the work of Brolley et al.[11] on the fission of Np^{237} by 14.3 Mev neutrons it was found that the light and heavy fragments do not have identical distributions. However, the technique used in their experiment was incapable of ensuring a reliable solution of the problem.[4] We attempted to compare the directions in which light and heavy fragments were emitted from the fission of U^{238} induced by 3-Mev neutrons, since our experimental conditions permit us to distinguish a light fragment from a heavy fragment and to determine its direction of emission. The result was such that the number of emissions of a light fragment (relative to the total number of fissions) in the 0°, 90°, and 180° directions were 48 ± 3, 48.0 ± 2, and (49.8 ± 3)% respectively. It can be seen here that to within 3% the angular distribution of the light fragments is symmetrical with respect to 90° and does not differ from the distribution for heavy fragments.

Also included in our study was a comparison between the mean kinetic energy of both fragments that separated at an angle of 0° to the neutron beam and the kinetic energy of fragments that separated at 90° to the beam, for mass ratios between 1.3 and 1.6. The total kinetic energy of both kinds of fragments that separated at 0° proved to be on the average 0.9 ± 0.5 Mev greater than the energy of the fragments that separated at 90°.

In conclusion the authors wish to express their gratitude to Yu. A. Selitskii for preparing the uranium target.

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174