Angular Distribution of the Uranium Fission Fragments Produced by High-Energy Neutrons

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MANY investigations made in the past few years have shown that the fragments of heavy nuclei fissioned by either charged or neutral medium energy (up to 20 mev) particles display a parallel anisotropy relative to the direction of the bombarding beam.[1,2] It was also established that this orientation becomes perpendicular[3,4] for uranium at incident-proton energies of 460 mev and higher. This communication reports on the results of analogous experiments with fission of uranium by high-energy neutrons.

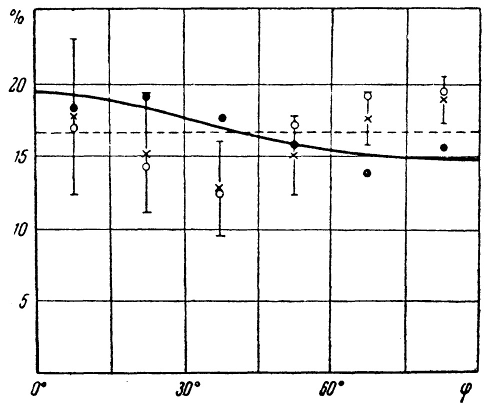
Plates coated with fine-grain nuclear emulsion P–9 impregnated with uranium salt were exposed to a collimated beam of neutrons obtained by charge-exchange between 680 mev protons and a beryllium target. The plane of the emulsion was parallel to the neutron beam. The plates were exposed behind a concrete wall in a supplementary holder made of cadmium and boron. The neutron sensitivity of the emulsion, judged from the number of π-μ decay events, was approximately 25–30 mev.

The angles between the fission fragments and the projection of the beam on the plane of the field of view were measured. Whenever the fragments subtended an angle less than 180°, the angle was read from the line joining the ends of their traces, so as to make the distribution approximate a center-of-mass system. The observation results are given in the Table, where the angle of distribution is given separately for "single" and "star" cases, (i.e., fissions not accompanied or accompanied by emission of one or several charged particles). The next to the last line of the Table gives the anisotropy coefficient determined as the ratio of the number of events occuring at 45–90° angles to the number of events with angles in the 0–45° interval; the statistical errors are also indicated. Even though the latter are indeed great, one is immediately struck by the fact that this coefficient systematically exceeds unity for all groups of "star" fissions.

Angles of projection, deg \ Number of rays	0	1	2	3	4	5–6	Number of "star" fissions	Total number of fissions
0—15	128	69	20	9	4	1	103	231
15—30	127	60	23	7	—	3	93	220
30—45	119	52	28	5	6	1	92	211
45—60	111	61	25	11	2	2	101	212
60—75	105	66	26	15	4	3	114	219
75—90	121	81	29	9	3	2	124	245
Всего	711	389	151	56	19	12	627	1338
Anisotropy coefficient	0.90	1.15	1.13	1.50			1.18	1.03
Statistical errors . . .	±0.07	±0.12	±0.20	±0.32			±0.10	±0.06

A method described in Ref. 5 was used to convert the observed angular distribution in a plane to a three-dimensional one. The Diagram shows the resulting angular dependence of the fragments of single and "star" fissions. For comparison, the Diagram shows the results of observations of fission of uranium by 460 and 660 mev protons taken from Refs. 3 and 4 and transformed by the above-mentioned method to obtain the three-dimensional picture. Although approximately the same number of fragments due to fission by high-energy neutrons escapes at 0° as at 90°, there is an obvious anisotropy in their distribution, similar to that obtained by fission with fast protons, where the anisotropy coefficient is 1.27 ± 0.05. The lower perpendicular directivity of neutron-induced fission can be fully explained by the complex energy make-up of the bombarding beam. The distribution of single fissions is in good agreement with the relationship obtained in Ref. 1, for uranium fission with neutrons up to 14 mev.

Based on data of the ray distribution of the fission events produced by 140–660 mev protons,[6] and assuming that the distribution obtained for fissions by neutrons of the same energy would be similar, one can obtain the general distribution from the number of rays produced in the fission of uranium by a neutron beam having a spectrum of the form given in Ref. 7, using at the same time the known relationship for $\sigma_f(E)$.[8] The distribution so computed agrees with that observed. A considerable contribution to the number of single fissions is made here by relatively low-energy neutrons which indeed determine the character of the angular anisotropy. Increasing the energy of the incident neutrons increases the proportion of events corresponding to a higher excitation of the fissioning nucleus, and the parallel anisotropy is replaced by a perpendicular one, in the sense defined above.



Angular distribution of fragments relative to the direction of the incident particle at a 15° angle interval and per unit solid angle: O—proton-induced fission, per Refs. 3 and 4, ●—neutron-induced "single" fissions, ×—neutron-induced "star" fission. The distribution of fragments as per Ref. 1 (solid curve) and the isotropic distribution (dotted line) are shown. The statistical errors are indicated for star fissions. The points corresponding to the proton experiments have errors that are approximately half as large.

We also determined the anisotropy in the angular distribution of the particles that accompany the fission of uranium nuclei, and compared them with the corresponding experimental data on proton-induced fission by protons.[6] The observed directivity of the particles produced in single-ray fissions is high—the forward to backward ratio is 2.0 ± 0.2; this ratio becomes 1.7 ± 0.2 for 2-ray fissions and 1.3 ± 0.2 for multiple-ray fissions. Calculations analogous to those made for the ray distribution, show that these quantities would result from experiments with a proton beam of a similar spectral composition.

One must thus assume that the anisotropy in the escape of fragments, the distribution as obtained from the number of particles accompanying the fragments, and the directivity of these particles are approximately the same whether the uranium nuclei are fissioned by high-energy neutrons or by protons of the same energy.

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150

On Molecular Neutronoscopy

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THE use of high-power short monoenergetic neutron pulses makes it possible now to devise a new method, one that can be called "molecular neutronoscopy," for research on the structure and properties of molecules.

The idea in this method is to subject the molecules under investigation to bombardment by short "packets" of monoenergetic neutrons ($E_0 \approx$ 1–10 ev) and to determine the binding energy of the molecules, the probability of various molecular conversions induced by the neutrons, and certain other characteristics (mentioned below) from the type of the time-of-flight spectrum and of the angular distribution of the scattered neutrons. The method proposed resembles most closely in its potentialities and means of realization the investigation of Debye levels of crystal lattices with the