ANISOTROPY IN THE FISSION OF BISMUTH AND URANIUM IRRADIATED BY 660-Mev PROTONS

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Submitted to JETP editor August 25, 1960

J. Exptl. Theoret. Phys. (U.S.S.R.) 40, 1250-1252 (May, 1961)

The angular distribution of fission fragments from bismuth and uranium irradiated by 660-Mev protons was studied using nuclear emulsions. The perpendicular anisotropy coefficients were found to be 0.02 ± 0.06 and 0.04 ± 0.07 for bismuth and uranium respectively.

In the irradiation of nuclei by medium-energy particles, emission of fission fragments is observed predominantly at angles of 0 and 180° to the direction of the particles (longitudinal anisotropy).[1] This is due to the fact that the bombarding particle introduces an angular momentum perpendicular to the beam direction into the nucleus.[2-4] With increasing excitation energy of the fission, the angular distribution of the fragments tends to become isotropic.[4]

In the irradiation of uranium by 460-Mev protons[5] and 660-Mev protons,[6] and of tantalum by 450-Mev protons,[7] emission of fission fragments was observed predominantly at right angles to the beam (perpendicular anisotropy). A weak predominance of particle emission at 90° was observed for asymmetric fission in the irradiation of uranium and sodium by 155-Mev protons.[8] At the same time, a small longitudinal fission anisotropy was observed* in the irradiation of bismuth by 450-Mev protons.[9,7]

An explanation of the perpendicular anisotropy as being the result of a glancing collision of a fast bombarding particle with the nucleon of the nucleus has been proposed.[11] One of the particles taking part in the collision moves with a small velocity and at right angles, and is absorbed in the nucleus. The flux of such particles leads to an anisotropy longitudinal with respect to their direction and perpendicular with respect to the direction of the bombarding particles. However, according to such a mechanism, the perpendicular anisotropy could be expected only in fission with small excitation energies.[10]

In the present experiment, the fission anisotropy was studied using nuclear emulsions P-9 (ch) in the irradiation of bismuth by 660-Mev protons. For comparison, and in order to increase the accuracy of data obtained earlier,[6] the anisotropy of the fission of uranium induced by 660-Mev protons was studied with large statistics in the following three variants: for all fission events, for single fissions ($n_{\alpha p} = 0$), and for fissions with the emission of charged particles ($n_{\alpha p} \geq 1$). In order to check the method, the angular distribution of fission fragments in the irradiation of uranium with 14-Mev neutrons, i.e., in the energy range where the character of the anisotropy has been sufficiently well studied, was carried out.[1] The angles φ between the direction of the bombarding particle and the projection of the line passing through the end of the fission fragment ranges were measured. (This line coincides roughly with the direction of emission of fragments in the system of the nucleus undergoing fission.) The angular distribution in space, e.g., of a type $W(\theta) = 1 + C\sin^2\theta + D\sin^4\theta$, transforms in the projection into a distribution

$$\omega(\varphi) = 1 + c\sin^2\varphi + d\sin^4\varphi,$$
$$c = \tfrac{2}{3}(C + \tfrac{2}{5}D)/(1 + \tfrac{1}{3}C + \tfrac{3}{15}D),$$
$$d = \tfrac{8}{15}D/(1 + \tfrac{1}{3}C + \tfrac{3}{15}D). \qquad (1)$$

Using the method of least squares we found the anisotropy of the measured angular distribution of the projections of the emission directions of the fragments. From the anisotropy of the projections, we can transform to anisotropy in space using Eq. (1). The results obtained are shown in the table.

The excitation energy of nuclei at 660-Mev proton energy was found from the calculated relation between the longitudinal component of the momentum and the excitation energy.[7] The longitudinal component of the momentum of a nucleus was determined experimentally.[12] The value of the longitudinal anisotropy in the case of 14-Mev neutrons

*The recent report[10] of a systematic error in reference 9 makes the results given there uncertain.

	Number of fission events		Excitation energy, Mev	Type of angular distribution	Observed anisotropy
U + n, E = 14 Mev	Total:	3130	18.8	$1 + B\cos^4\theta$	$B = 0.46 \pm 0.11$
Bi + p, E = 660 Mev	Total:	5650	170±25	$1 + C\sin^2\theta$	$C = 0.02 \pm 0.06$
	Total:	4441	140±15		$C = 0.04 \pm 0.07$
U + p, E = 660 Mev	$n_{\alpha p} = 0$	: 2083	85±20	$1 + C\sin^2\theta$	$C = 0.05 \pm 0.11$
	$n_{\alpha p} \geqslant 1$	: 2358	170±25		$C = 0.01 \pm 0.10$

B = 0.46 ± 0.11 is in good agreement with the value W(0°)/W(90°) − 1 = 0.40 ± 0.14 found using an ionization chamber.[13]

In irradiation with 660-Mev protons, the perpendicular anisotropy is C = 0.02 ± 0.06 for bismuth and C = 0.04 ± 0.07 for uranium, i.e., the angular distribution of fission fragments is isotropic within the limits of experimental error. The results for uranium differ from the earlier data,[6] where a marked preponderance of emission of fragments at right angles was observed, i.e., W(90°)/W(0°) − 1 = 0.33 ± 0.19, increasing slightly with increasing excitation energy.

The reason for the discrepancy of the results, apart from statistical errors, may also be systematical errors due to the fact that in scanning a horizontal emulsion strip, the ends of the fragment tracks from fission events fall into the field of view, whereas the center of the event is outside the field of view, either above or below it. The probability of such an additional incidence increases with the angle between the emission of fission fragments and the direction of the strip. The detection of such events leads to a false perpendicular anisotropy (~ 0.12 for a field of view of 100 μm). In the present measurements, the emulsions were scanned in two mutually perpendicular directions to avoid possible systematical errors.

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Translated by H. Kasha
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