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ANGULAR DISTRIBUTION OF FISSION FRAGMENTS IN FISSION INDUCED BY HEAVY IONS

V. A. DRUIN, Yu. V. LOBANOV* and S. M. POLIKANOV*

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The ratio of the yield of fission fragments emitted at angles of 135 and 90° was measured in the fission of gold nuclei induced by carbon and oxygen ions and also in the fission of U^{238} by carbon ions. Measurements were made of the ranges of the fission fragments from the same two reactions. Experimental values of the coefficient of anisotropy of the fission fragments are compared with theoretical values obtained on the basis of statistical theory.

1. INTRODUCTION

THE angular distribution of fission fragments is determined by the relation between the predominant orientation of the spin of the compound nucleus and the direction of fission. For a given total angular momentum the angular distribution depends on the magnitude of the component of the total angular momentum along the direction of fission.[1,2]

In experiments carried out in recent years an anisotropy of the angular distribution of fission fragments was observed in the case of fission of nuclei induced by neutrons,[3,4] protons,[5-7] α-particles,[8] C^{12} nuclei,[9] and γ quanta.[10] It was found that in the case of fission induced by nucleons the fission fragments are emitted primarily along the beam of particles giving rise to fission, whereas in the case of photofission they are emitted at right angles to the beam of γ quanta. This difference is due to the different orientation of the spin of the compound nucleus. The degree of anisotropy depends primarily on the magnitude of the angular momentum introduced by the bombarding particle.

In the present experiments, which are a continuation of the work in reference,[9] we have measured the anisotropy of the distribution of fission fragments in the case of fission induced by C^{12} and O^{16} ions. In this case the compound nuclei produced have larger values of angular momentum than when light particles are used, and this may lead to considerable anisotropy in the angular distribution of fission fragments.

The experimental results are presented below.

2. EXPERIMENTAL TECHNIQUE

The measurements were carried out using the internal beam of the 150-cm cyclotron of the U.S.S.R. Academy of Sciences. The energy of the accelerated particles at the largest radius amounted to 78 and 100 Mev for the C^{12} and O^{16} ions, respectively. The fission fragments were recorded by the activation method by means of a simple arrangement which is shown schematically in Fig. 1. The fission fragments were collected on aluminum foils situated at angles of 90 and 135° with respect to the direction of the beam. The relative yield of fission fragments at a given angle

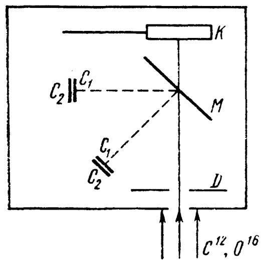

FIG. 1. Schematic diagram of the experiment. K – collector, M – target, D – diaphragm, C_1 – collector I, C_2 – collector II.

was determined by means of the intensity of β-radiation arising as a result of the decay of the fission fragments. The β particles were recorded by means of an MST-17 end-window counter. Since thick ($\sim 10\,\mu$) films of gold and natural uranium were used for targets, the aluminum collectors received fission fragments from a layer of fissionable material equal to the range of the fission fragments in the given substance. On taking this into account, the degree of angular anisotropy may be expressed in terms of the experimentally observed activation of the collectors by means of the following relation:

$$N(135°)/N(90°) = (A_{135°}\sigma_1 R_{90°}/A_{90°}\sigma_2 R_{135°})\cos 45°,$$

where $A_{135°}/A_{90°}$ is the ratio of the β activities of the collectors situated at corresponding angles, $R_{90°}$ and $R_{135°}$ are the ranges of the fission fragments at angles of 90 and 135°, σ_1 and σ_2 are the average fission cross sections in the layer of the fissionable substance from which the fission

*Joint Institute for Nuclear Research Institute Staff.

Reaction	Particle energy, Mev	$\frac{A_{135°}}{A_{90°}}$	$\frac{N(135°)}{N(90°)}$	$\frac{F(141°)}{F(102°)}$	$R_{135°}$, μ Al	$R_{90°}$, μ Al
Au (C^{12}, f)	66	1.03±0.06	0.92±0.08	1.00±0.09	10.1±0.7	10.9±0.9
	78	1.48±0.04	1.20±0.06	1.34±0.07		
	111*			1.62		
Au (O^{16}, f)	85	1.05±0.05	0.99±0.06	1.08±0.07	9.6±0.8	10.9±0.9
	100	1.23±0.05	1.09±0.06	1.23±0.07		
U^{238} (C^{12}, f)	78	1.18±0.05	1.05±0.06	1.11±0.06	11.1±0.7	11.2±0.8

*Data due to Reynolds (private communication).

fragments are collected by foils situated respectively at angles of 90 and 135°.

In order to calculate the coefficient of anisotropy it is necessary to know the ranges of the fission fragments and the dependence of the fission cross section on the energy. The ranges of the fission fragments were determined in separate experiments, when the thickness of the collectors I was less than the range of the fission fragments (2, 5, 8, and 10 μ). The ratio of the β activities of the first and the second collector is related to the range of the fission fragments in the following manner:

$$R = d(1 + A_2\sigma' / A_1\sigma''),$$

where d is the thickness of collector I, σ′, σ″ are the average fission cross sections in the layer of the fissionable material, the fission fragments from which are collected on foils II and I respectively.

The energy dependence of the fission cross section was measured in terms of the activation of the collector at various ion energies.

Chemical separation of individual fission fragments was not carried out. However, the fact that the ratio of the activities of the collectors at angles of 135 and 90° practically did not vary with time points to the small dependence of the angular anisotropy on the mass ratio of the fission fragments.

3. EXPERIMENTAL RESULTS AND DISCUSSION

As a result of the experiments which were carried out we have obtained data on the degree of angular anisotropy of fission fragments produced in the fission of gold by carbon and oxygen ions and in the fission of U^{238} by carbon ions. The experiments with gold were carried out at two different ion energies.

The experimental results are presented in the table. In this table in column 5 we have given the values of the coefficient of anisotropy in the center of mass system at corresponding angles. The errors shown are determined principally by geometric factors (dimensions of the ion beam, the accuracy of the placement of the collector with respect to the β counter, etc.) and by the statistical accuracy of measurement.

The coefficients of anisotropy obtained by us were compared with theoretical values obtained on the basis of the statistical theory.[2] From Fig. 2 it is seen that at a compound nucleus temperature of 1.0 to 2.0 Mev the rotational constant

$$B = \frac{\hbar^2}{2J_{\mathrm{eff}}} \quad \left(\frac{1}{J_{\mathrm{eff}}} = \frac{1}{J_{\parallel}} - \frac{1}{J_{\perp}}\right)$$

($J_{\parallel}$ is the moment of inertia of the compound nucleus with respect to the symmetry axis, $J_{\perp}$ is the moment of inertia of the compound nucleus with respect to an axis perpendicular to the symmetry axis) does not exceed 4 kev. This enables us to conclude that the moment of inertia of the compound nucleus at the saddle point is close to the moment of inertia of a solid.

On assuming that fission is fundamentally symmetric we can estimate the kinetic energy of the fission fragments on the basis of the experimentally observed values of their ranges. In this case the kinetic energy of the fission frag-

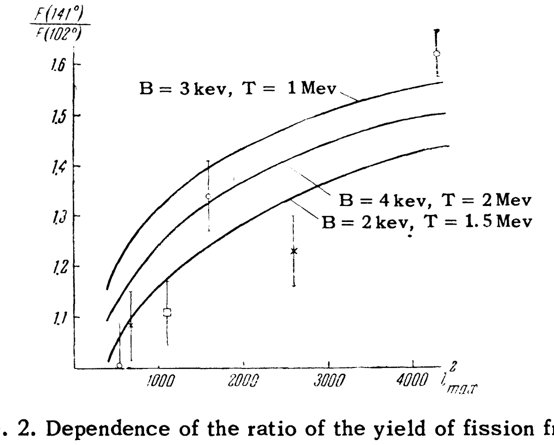

FIG. 2. Dependence of the ratio of the yield of fission fragments at angles of 141 and 120° (center of mass system) on the maximum angular momentum of the compound nucleus l^2_{max}. The curves have been calculated by means of the formulas of reference 2. Experimental values: o – for the reaction Au(C^{12}, f), × – for Au(O^{16}, f), □ – for U^{238} (C^{12}, f).

ments is equal to ~ 110 Mev for the reactions Au (C^{12}, f), Au (O^{16}, f) and ~ 140 Mev for the reactions $U^{238}(C^{12}, f)$.

In conclusion we consider it our pleasant duty to express our gratitude to Professor G. N. Flerov for directing the present work, and also to V. M. Strutinskiĭ and to G. A. Pik-Pichak for discussion of results.

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