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THE TERNARY FISSION OF ^{235}U INDUCED BY THERMAL NEUTRONS*

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Abstract: An investigation has been made of the ternary fission of ^{235}U in nuclear emulsions and solid state track detectors sensitive to particles of $A > 4$ and $A \geqslant 16$, respectively. The uranium target was homogeneously distributed throughout the emulsion, or vacuum evaporated on the two foils of the solid state detector (polycarbonate). On the basis of calculated ternary events and cases of scattering from the ternary fission a comparison is made of the results obtained by means of the two detectors. The yield of ternary fission relative to binary fission is determined to be $(8.0 \pm 0.4)\ 10^{-5}$ in the emulsion, and $(7.4 \pm 0.2)\ 10^{-5}$ in the polycarbonate detector.

1. Introduction

Investigation of low-energy ternary fission whose fragments are heavy charged particles is difficult by the very low frequency of the events as well as by the presence of events of elastic scattering of binary fission fragments on target and detector nuclei. So far the following methods have been used to study the problem: nuclear emulsions[1, 2, 3], coincidence detectors of individual particles[4], solid state track detectors[5, 6] and a radiochemical method[7], of which the first three have given positive results on the existence of the ternary fission. The data obtained by these methods on the frequency of ternary fission relative to binary fission are ranging from $10^{-3} — 10^{-6}$. To get a more complete knowledge of the ternary fission induced by thermal neutrons we have investigated the fission of ^{235}U induced by monoenergetic neutrons of energy of 0.085 and 0.090 eV with photonuclear emulsions as well as with solid state track detectors and compared the results obtained.

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2. Experimental

The use and treatment of the detectors. The Ilford KO nuclear emulsion used was in gel form enriched in uranium[3]. The polycarbonate detector (makrofol) was used in the form of a sandwich consisting of two 200 μm foils of a size of 3 × 4 cm²; uranium layer several hundred Å thick was vacuum evaporated on the interior side of one of the foils. The sandwiches were glued to one another along the shorter edges by means of methylene chloride[8]. After exposure the photonuclear emulsions were developed in amidol developer, so that no alpha particle tracks were registered. The uranium target in the solid state detector was dissolved in HNO_3 and thereupon the foils were treated with 5N NaOH at 60 °C for 40 minutes. After the treatment with NaOH the detector foils were rinsed in water and ethyl alcohol. Scanning of the emulsions and solid state detectors was carried out with a microscope under magnification of 100 · 16, 5 · 1.25 and 53 · 16, 5 · 1.25, respectively.

Discrimination of ternary fission from scattering events. Ternary events (T^+) registered in the two detectors belong to ternary fission or to scattering of fission fragments on detector nuclei, which in emulsion are seven (C, N, O, Br, Ag, I, U) and in polycarbonate two (O, U). Also accidental events (T^-), produced by coincidence of binary events[9], have been registered in the case of polycarbonate. Discrimination of T^+ and T^- events was made during scanning. Discrimination of ternary fission from scattering events was in principle carried out in the way described in previous works[1, 2, 3]. The projected track lengths (Rx_1, Rx_2, Rx_3), projected angles (β_1, β_2, β_3) and Z-components (Z_1, Z_2, Z_3) (Fig. 1) were measured for all three-prong events. Multiplying the measured lengths by the scale magnification of the microscope, and Z-components

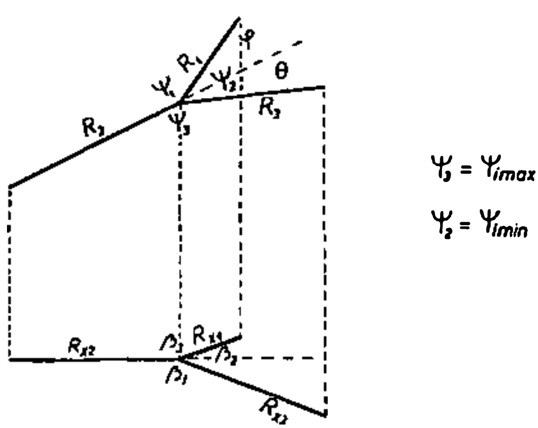

Fig. 1.

by the shrinkage factor of the emulsion or by the correction factor due to the index of refraction in the makrofol, we obtained the quantities for calculation of tan α (dip). Using the angles α and β for all the three tracks, the solid angles ψ_1, ψ_2 and ψ_3 are calculated by the relation,

$$\cos \psi = \cos \alpha_1 \cos \beta_1 \cos \alpha_2 \cos \beta_2 + \cos \alpha_1 \sin \beta_1 \cos \alpha_2 \sin \beta_2 + \sin \alpha_1 \sin \alpha_2. \quad (1)$$

Calculation of the error in solid angle was carried out by using the total differential of expression 1:

$$\Delta\psi_i = \frac{\partial \psi_i}{\partial Z_a} \Delta Z_a + \frac{\partial \psi_i}{\partial Rx_a} \Delta Rx_a + \frac{\partial \psi_i}{\partial Z_b} \Delta Z_b + \frac{\partial \psi_i}{\partial Rx_b} \Delta Rx_b + \frac{\partial \psi_i}{\partial \beta_a} \Delta\beta_a + \frac{\partial \psi_i}{\partial \beta_b} \Delta\beta_b, \quad (2)$$

where a and b are the indices of the neighbouring tracks between which the angle is measured, and Δz, ΔR and $\Delta\beta$ are the errors in measurement. The maximum error ($\Delta\psi_i$) in angles ψ_1, ψ_2, ψ_3 was taken to be the error in the total solid angle ($\Sigma \psi_i$). By coplanar ternary events we meant those satisfying the condition

$$| 360 - \Sigma \psi_i | \leqslant \Delta \psi_{i\,max} . \quad (3)$$

The angles θ and φ were calculated by the relations

$$\theta = 180 - \psi_{i\,max} \quad (4)$$

$$\varphi = \psi_{i\,min} - \theta , \quad (5)$$

where θ and φ have the corresponding errors

$$\Delta \theta = \Delta \psi_{i\,max} \quad \text{and} \quad \Delta \varphi = \Delta \psi_{i\,min} .$$

Discrimination of events of fission fragment scattering on target and detector nuclei from ternary fission was made by using the expression

$$\tan \theta = \frac{\sin 2\varphi}{\frac{M_f}{M_t} - \cos 2\varphi} , \quad (6)$$

where θ and φ are experimental values for each T^+ event, M_f are the mass numbers of the fission fragments

$$84 \leqslant M_f \leqslant 152 , \quad (7)$$

and M_t are the mass numbers of the chemical elements of the target and detector.

By ternary fission are meant those events which, within the limits of error in θ and φ, did not satisfy expression 6. For such cases the total energy was calculated by the relation

$$E = 1.22\,R + 0.369\,R^2 \tag{8}$$

for nuclear emulsions[1] and by the relation

$$E = 0.22\,R^2 + 0.42\,R\,. \tag{9}$$

for polycarbonate detector[10].

For the entire procedure a computer programme was written using as input data for each event only measured values.

3. *Results and discussion*

Table 1 gives the results of the analysis of fission in the nuclear emulsion and makrofol. Since the errors in angles θ and φ for events with $R \leqslant 4.9$ μm in emulsion, or $R \leqslant 5.6$ μm in makrofol, are so large that no discrimination can be made of ternary fission from cases of scattering, the obtained results on the frequency of ternary fission represent a lower limit. It turned out

Table 1

Detector	Number of observed binary fissions	Number of threeprong events	Number of ternary fissions events	T/B
	B	T^+	T	
Emulsions	273000	1780	22	$(8{,}0 \pm 0{,}4)\,10^{-5}$
Polycarbonate (makrofol)	433000	120	32	$(7{,}4 \pm 0{,}2)\,10^{-5}$

that the errors in θ and φ are also large for events with short tracks seeming to lie in the plane of microscope, which were the only ones taken for analysis in previous works[2,3,6].

The values of frequency of ternary fission in the two detectors are also close to each other; one ternary fission event (T) was found per about 12500 and 13500 binary fission (B) events in emulsion and makrofol, respectively. The difference in the T/B ratio is accounted for by the fact that in the case of makrofol no correction was made for V-events, which represent scattering events for which one fragment is undetected or emitted in parallel to the detector foils, or ternary fission[5]. This difference may also be due to the different registration threshold in emulsion and makrofol.

Ternary fission in the two detectors is asymmetric, since no events with $\psi_{i\,max} = \psi_{i\,min}$ have been found. In emulsion $\psi_{i\,max} = 159 \pm 16$, $\psi_{i\,min} = 41 \pm 17$ while in makrofol $\psi_{i\,max} = 147 \pm 11$, $\psi_{i\,min} = 71 \pm 11$.

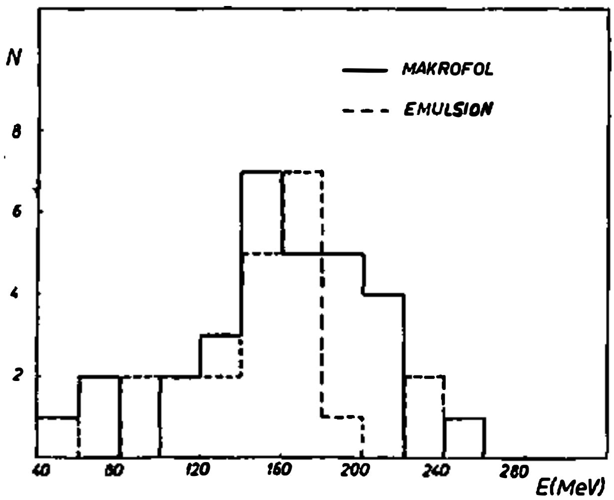

Fig. 2.

The mean total energy of the fragments of ternary fission in emulsion and makrofol amounts to 150 MeV and 161 MeV, respectively.

The large straggling of the results on the total energy of the fragments of ternary fission in the two detectors (Fig. 2) is explained by the limitations of expressions 8 and 9, which are valid for fission fragments with $30 \leqslant Z \leqslant 62$, i.e. for the fragments of symmetric binary fission.

Our results on the frequency of ternary fission obtained with the two detectors are close to those obtained with coincidence counters[4] as well as to those obtained for uranium photofission[5].

References

1) P. Demers, Jonographie, Les presses Universitaires des Montreal (1958);
2) M. Jurić, Bull. B. Kidrič, **15** (1964) 217;
3) M. Jurić and R. Antanasijević, VI Inter. Conf. on Corp Phot., Florence, C.E.P.I., Roma, p. 101 (1966);
4) M. L. Muga, C. R. Rice and W. A. Sedlacek, Phys. Rev. **161**, (1967) 1266; M. L. Muga, C. R. Rice and W. A. Sedlacek, Proceedings of a Symposium Vienna, 28 July — 1 August (1969) p. 107;
5) L. Medveszky, G. Somogyi and G. Götz, Kiadja a Magyar Tudomanyos Academia Atommag Kutato Intezete, Debrecen, 1969/1;
6) M. Jurić, R. Antanasijević and J. Vuković, VII Conf. on Corp. Phot. Barcelone, (1970);
7) R. W. Stoenner and M. Hillman, Phys. Rev. **142** (1966) 716;
8) M. Debeauvais, R. Stein and J. Ralarosy, P. Cüer, Nucl. Phys. **A 90** (1967) 186;
9) R. Brant et al., C.E.R.N. Heidelberg—Naples—Warsaw Collaboration J. de Phys. **31** (1970) 21;
10) J. Ralarosy et al., J. de Phys. **30** (1969) 1.

TERNARNA FISIJA ^{235}U IZAZVANA TERMALNIM NEUTRONIMA

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Sadržaj

Ispitivanje ternarne fisije ^{235}U vršeno je nuklearnim emulzijama i čvrstim detektorima osetljivih na čestice $A > 4$ i $A > 16$, respektivno. Meta urana je homogeno raspoređena u emulziji, odnosno vakuumski naparena između dve folije čvrstog detektora (polikarbonata). Napravljen je program za računsku mašinu kojim se obračunavaju svi ternarni događaji i vrši se izdvajanje slučajeva rasejanja od ternarne fisije. Na osnovu toga upoređeni su rezultati dobijeni sa oba detektora. Određen je prinos ternarne fisije u odnosu na binarnu fisiju koji u slučaju emulzije iznosi $(8{,}0 \pm 0{,}8) \cdot 10^{-5}$ a u polikarbonatnom detektoru $(7{,}4 \pm 0{,}2) \cdot 10^{-5}$.