KINETIC ENERGY OF FRAGMENTS AS A FUNCTION OF ALPHA-PARTICLE ENERGY IN THE TERNARY FISSION OF URANIUM

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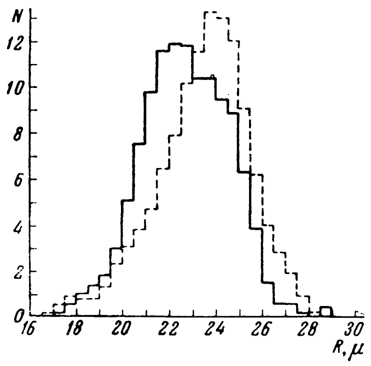
A study is made of the dependence of the overall range of fragments in the ternary fission of uranium by thermal neutrons on the energy of long-range α particles. The data obtained serve as a basis for a discussion of the mechanism of ternary fission.

IN the study of the energy distribution of U^{235} fission fragments [1] the following relation was obtained between the total kinetic energies of the fragments in binary and ternary fission of U^{235} by thermal neutrons:

$$E_d = E_t + E_\alpha,$$

Where E_d is the most probable total kinetic energy of the fragments in binary fission, E_t the same for ternary fission, and E_α the most probable kinetic energy of a long range α particle. It was suggested in the same paper that this relation should be valid in the more general case, and not only for the most probable values. This hypothesis, however, calls for experimental verification.



Summary-range distribution of the fragments of ternary fission of U^{235} by thermal neutrons: Dashed line – for long-range alpha particles in the energy intervals 6–14 MeV, solid line – for long-range alpha particles in the energy interval 17–30 MeV.

To this end we used the nuclear photoemulsion method. In P-80 plates impregnated with uranium salt and exposed in the thermal column of the reactor, we observed the ternary fissions of U^{235} by thermal neutrons. For the alpha-particle tracks terminating in the emulsion, we could find the particle energies and also measure the ranges of the fission fragments. Altogether 300 known-range stopped particles were observed. Their energy spectrum was broken up into three intervals, each with approximately the same number of events: 6—4 MeV (with average energy 10.4 MeV), 14—17 MeV, and 17—30 MeV (with average energy 21.0 MeV). For each of the indicated alpha-particle energy intervals we plotted the distribution of the summary fission fragments. The results of the observations, reduced by the method of Ferreira and Woloschek [2] are shown in the figure for the alpha-particle energy intervals 6—14 and 17—30 MeV. The distributions are normalized to the same number of fragments. The diagram shows clearly the shift in the most probable fission-fragment ranges as a function of the average energy of the long-range particle.

Inasmuch as the variance of the fragment ranges is connected with the variance of their kinetic energy, one can estimate the value of the obtained shift, which amounts to about 10 MeV. Thus, it can be assumed that Eq. (1) remains valid not only for the most probable values of the alpha-particle energies, but also in other portions of their energy spectrum. It follows therefore that the average alpha-particle energy will be higher if the nucleus breaks up at larger average distances between fragments (i.e., their summary kinetic energy is smaller) and vice versa.

Such a relation between the kinetic energies of the fragments and of the fission alpha particles does not agree with the ideas that follow from the model suggested in 1948 by Tsien [3]. In order to explain the results of the experiments, Tsien confined himself to an examination of a system of three charged particles is contact, formed as a result of vibrations of a fissioning nucleus. These particles are at rest in the initial instant of time and move apart under the influence of the Coulomb forces. An account of the asymmetry of the fission determines the position of the maximum and the distribution of the alpha particles relative to the line of fragment scattering. Furthermore, the larger the distance from the central alpha particle to the fission axis at the initial instant, the greater the kinetic energy acquired by this particle as a result of the geometrical addition of the forces, and the smaller the distance between the fission fragments. As was already indicated this consideration contradicts the results of the present investigation. Tsien's model of ternary fission, as was noted in one of our earlier papers [4], also contradicts the relation between the angular dispersions of the alpha particles and their energies.

The pure Coulomb interaction, on which the model is based, although capable of explaining several regularities, considers only the second stage of the process—the scattering of three produced charged fragments, and says nothing of the compound fission mechanism, and how the total energy of the alpha particle becomes appreciably higher than its initial total energy.

The presently available experimental data offer evidence that binary and ternary fission of heavy nuclei are organically related. The emission of a long-range alpha particle, as noted by Yu. F. Romanov [5], does not lead to an appreciable redistribution of the nucleons in the fragments, but is a process that occurs in the neck of the nucleus. The mechanism of alpha-particle emission itself is related by the author to the lowering of the potential barrier in the region of the neck of the nucleus, which likewise cannot bring the alpha particle to a state with larger total energy.

In our opinion, the idea that to obtain an appreciable alpha-particle energy it is not necessary to realign the fragments and to change their form, as compared with binary fission, indicates that this process result only from the collective motion of the individual fragments, at the expense of motion that is somehow connected with their subsequent kinetic energy. The only motion of this type can be oscillation of a dumbell-shaped nucleus. The increase in the effective distance between the centers of the fragments, and consequently the reduction of their kinetic energy with increasing energy of the alpha particle, can be regarded as a confirmation of this conclusion.

The group of nucleons contained in the neck of the dumbell-shaped nucleus is in the field of the attractive forces of both fragments and, as a result of the short-range action of the nuclear forces, is the only binding link between the fragments. With increasing effective distance between the fragment centers, the potential energy of such a group will increase; the work expended to move the fragments apart can be regarded in part as work done to impart additional potential energy to this group. With increasing energy of the alpha particle produced by the four nucleons in the neck, the probability of its leaving the nucleus will increase, and this will be accompanied by the observation of ternary fission. The form of the energy distribution of the alpha particle will then depend on the form of the vibrations of the nucleus and on the penetrance of the potential barrier, and for large r_{eff} the alpha particle can acquire an energy equal to the energy of the potential barrier of the fissioning nucleus (or the summary barrier of the two fragments), while the width of the angular distribution curve as a function of the alpha-particle energy depends on the possible directions of emission of the alpha particles from the neck for different r_{eff}.

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