ENERGY DISTRIBUTIONS OF PHOTOFISSION FRAGMENTS FROM U^{238} NUCLEI FOR BREMSSTRAHLUNG OF DIFFERENT MAXIMUM ENERGIES

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The bremsstrahlung spectrum with $E_{\gamma max}$ = 17.5, 30, and 50 MeV from a synchrotron was used to obtain contour diagrams of the kinetic-energy distribution of U^{238} photofission fragments. A double ionization chamber was used to detect the fragments. It was found that the kinetic energy of fragments emitted in symmetric fission is constant within 3 MeV when the mean excitation energy of the fissioning nuclei changes.

INTRODUCTION

FOR an understanding of the process of fission, the value of the kinetic energy associated with the internal motion in fissioning nuclei during the transition from the saddle point to the point of fragment emission is of importance. If this process takes place rapidly, i.e., during a time less than or comparable to the nuclear time, then it is, of course, meaningless to speak about the establishment of a statistical equilibrium during this process. Nevertheless, statistical methods are broadly applied to explain many properties of the fission process. If it is assumed that the conditions of statistical equilibrium are valid during the "descent" of the fissioning nucleus from the saddle point to the point of emission of the fragments, then according to the estimate of Fong,[1] the energy corresponding to the internal motion is 0.5 MeV. However, a number of authors, for example, Johansson,[2] express doubts as to whether this energy is large enough. As an argument supporting these doubts, reference is made to the experimental data (see [3] and [4]) on the kinetic energy accompanying the fission of U^{235} induced both by thermal neutrons and 14-MeV neutrons. In these experiments, it was shown by means of a calorimetric method that in the latter case the kinetic energy of the fission fragments from U^{235} is 6—7 MeV greater than in the former case. This fact was interpreted as a confirmation that part of the excitation energy of the nucleus undergoing fission is changed into kinetic energy of the internal motion, and therefore into the kinetic energy of the emitted fragments.

Subsequent measurements with the aid of an ionization chamber did not confirm the results cited above. Baranov, Protopopov, and Éĭsmont[5] found that the energy of fragments emitted from the fission of U^{238} induced by 3-MeV neutrons is approximately 2 MeV greater than the kinetic energy of fragments of U^{238} bombarded by 14-MeV neutrons for the asymmetric region of the fragment mass ratios.

We describe here an experiment in which the behavior of the kinetic energy of fragments from the photofission of U^{238} emitted in symmetric fission was studied.

1. EXPERIMENTAL METHOD

The experimental arrangement is shown in Fig. 1. It is similar to the experimental arrangement described previously (see [6]).

The geometry of the experiment and the use of a time-expanded γ beam made it possible to eliminate almost completely the background ionization arising from the passage of the γ beam through the effective volume of the chamber. A colloidal film spattered in vacuo with bismuth on both sides was used as the target. The thickness of the film together with the bismuth coating was about 30 $\mu g/cm^2$. A 100-$\mu g/cm^2$ layer of uranyl nitrate was deposited on one side of the film. The proper functioning of the entire arrangement and the resolving power of each of the two chambers was checked with the aid of the energy spectra of α particles emitted by U^{238} and U^{234}. A cathode-ray tube with two pairs of deflecting plates was used to record pulses from each of the fragments. In each series of measurements, for which we used bremsstrahl-

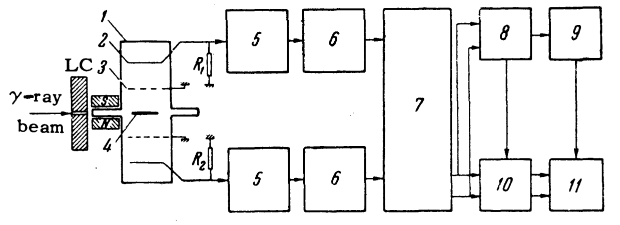

FIG. 1. Block diagram of the experimental arrangement: 1 – double ionization chamber, 2 – collecting electrodes, 3 – grounded shielding grid, 4 – high-voltage electrode with thin-film target, 5 – preamplifier, 6 – amplifier, 7 – time-selection circuit, 8 – coincidence circuit, 9 – intensity-gate circuit, 10 – pulse-height memory circuit, 11 – cathode-ray tube with two pairs of deflecting plates, LC – lead collimator, R_1 and R_2 – resistances across which the voltage pulse is developed.

ung of maximum energy 17.5, 30, and 50 MeV, we recorded 15,000–20,000 acts of fission.

2. DISCUSSION OF THE EXPERIMENTAL RESULTS

From the results of the experiment, we constructed the contour diagrams of the kinetic-energy distribution for each value of the maximum bremsstrahlung energy. The contour diagrams for $E_{\gamma max}$ = 17.5 and 30 MeV are shown in Fig. 2. It is seen from the contour diagrams that the most important change in the diagram as the energy is varied to a higher energy $E_{\gamma max}$ is the increase in the probability of the symmetric fission yield.

Since the energy spectrum of the γ rays producing the fission is continuous, it is necessary to estimate the mean excitation energy of the nuclei undergoing symmetric and asymmetric fission for each of the maximum energies. For this estimate, we used data on U^{238} photofission cross sections [7] and data on the structure of the bremsstrahlung spectrum for each of the three values of $E_{\gamma max}$. The calculations show that the mean excitation energy of the nuclei undergoing asymmetric fission remains practically constant with a change in $E_{\gamma max}$ and is 13.2, 14, and 14 MeV, respectively, for $E_{\gamma max}$ = 17.5, 30, and 50 MeV. Hence, under the conditions of our experiment, the kinetic energy of the emitted fragments for asymmetric fission, which is 169 MeV, did not change. This made it possible to use the position of the maximum of the energy distribution for fragments from asymmetric fission as a reference point on the energy scale. The position of the maxima of the energy distribution of fragments from symmetric fission was determined from their displacement relative to the maximum of the energy distribution for asymmetric fission.

This permitted the complete elimination of possible errors in calibrating the energy axis by means of the energy spectrum of the α particles from the target. The mean excitation energy of nuclei undergoing symmetric fission turned out to be 13.6, 17.0, and 21.4 MeV, respectively, for $E_{\gamma max}$ = 17.5, 30, and 50 MeV. The experimental results are shown in Fig. 3. The kinetic energies of the fragments emitted in symmetric fission are equal to 157 ± 3, 159 ± 3, and 160 ± 3 MeV, respectively, for $E_{\gamma max}$ = 17.5, 30, and 50 MeV; within the limits of experimental error, they can be con-

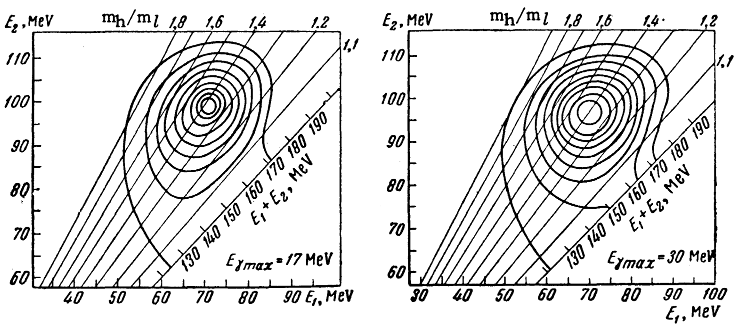

FIG. 2. Contour diagrams for the kinetic energy distribution of fragments for two values of the bremsstrahlung maximum energy. Each contour line corresponds to an increase in the fission probability by 0.1 (m_h and m_l are the masses of the heavy and light fragments)

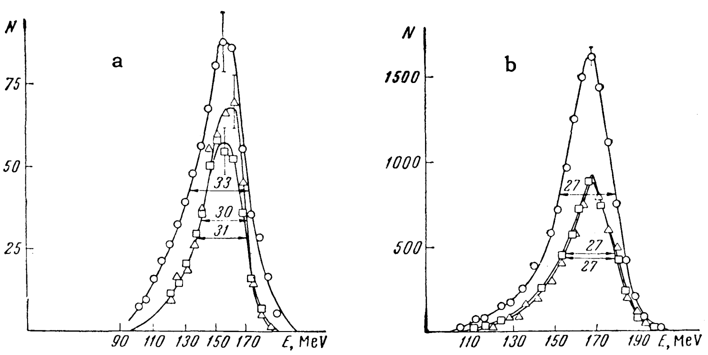

FIG. 3. Spectra of the total kinetic energy of photofission fragments for various brehmsstrahlung energies (the numbers indicate the half-widths of the peaks): a – symmetric (in mass) fission, b – asymmetric fission, □ – $E_{\gamma max}$ = 17.5 MeV, ○ – $E_{\gamma max}$ = 30 MeV, Δ – $E_{\gamma max}$ = 50 MeV.

sidered compatible with one another. Hence the kinetic energy of the fission fragments for medium excitation energies remains practically constant, within the limits of experimental error, as the excitation energy of the nuclei undergoing either asymmetric or symmetric fission changes.

It appears that further experiments could provide more precise information on this question; in this connection, it would be of interest to carry out experiments on the fission of various isotopes at different excitation energies.

Apparently, an estimate of the kinetic energy of the internal motion of the nucleus during its "descent" from the saddle point to the point of rupture of the "neck" can be made if the various factors affecting the half-width of the total kinetic energy distribution of the emitted fragments are considered. Without exception, all methods of measurement of the fission fragment kinetic energy for a fixed mass ratio give a considerable spread in this value. Consequently, it can be assumed that a large half-width of the distribution (not less than 15 MeV) is inherent in the very process of fission.

It is reasonable to assume that the kinetic energy of the fission fragments E_k is determined by the forces of Coulomb repulsion. If we denote the charges of the fragments by Z_1 and Z_2, we can write

$$E_k = Z_1 Z_2 e^2 / r_{\text{eff}},$$

where r_{eff} is the effective distance at which the fragments begin to acquire a kinetic energy due to the repulsive Coulomb forces. In this case the variation of the Coulomb energy δE_k for a given mass ratio of the fragments can occur as a result of the variation $\delta(Z_1 Z_2)$ and $\delta(r_{\text{eff}})$. The variation of the product of the charges cannot constitute an important quantity if we take into account the fact that no β^+-active nuclei are observed among the fission fragments for moderate energies of the fission-inducing agent. This experimental fact imposes sharp limitations on the possible variation of the charges. The variation in the Coulomb energy is then almost completely determined by the variation $\delta(r_{\text{eff}})$, which can attain 8% of the value $r_{\text{eff}} = 1.8 \times 10^{-2}$ cm. This value for r_{eff} follows both from the experimental estimates of the total kinetic energy of the emitted fission fragments and from theoretical calculations. If the uncertainty in the energy of the internal motion is connected with this uncertainty in the radius at which rupture occurs, then we have an indication of the lower limit for this energy, which is in order of magnitude equal to the uncertainty in this energy:

$$E_{\text{int}} \cong \hbar^2 / (\delta r)^2 2\mu = 0.5 - 0.8 \text{MeV},$$

where μ is the reduced mass of the fission fragments.

Such an estimate of the energy of the internal motion in the "descent" from the saddle point to the point of rupture of the "neck" is close to the statistical estimate and is evidence of the rather slow process of the "descent."

It should also be noted that if we wish to determine how the energy of the internal motion changes during the "descent" from the saddle point as a function of the initial excitation energy of the nucleus, then a more effective method of determining this relation experimentally would be to observe the change in the half-width of the energy distribution for a fixed mass ratio as the excitation energy of the nucleus changes.

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