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DISPERSION OF THE KINETIC ENERGY OF FISSION FRAGMENTS FROM HEAVY NUCLEI

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The effect of fragment rotational energy fluctuations on the dispersion of the total kinetic energy is considered. The estimates indicate that dispersion of the total kinetic energy of the fragments is due in an equal degree to fluctuations of rotational energy of the fragments and to fluctuations of the mean distance between the fragments during fission.

An investigation of the kinetic energy of fragments in the fission of heavy nuclei has shown that the value of this energy is subject to large fluctuations. The experimentally obtained width of the distribution of the total kinetic energy of the fragments at half its maximum value (ΔE_{kin}) is approximately 20 MeV.

The fragment kinetic energy is due essentially to the Coulomb interaction. One might think, however, that not all the energy of the Coulomb interaction goes over into the translational energy of the fragments. Deformed fragments can also acquire a rotational momentum as the result of the mutual Coulomb repulsion. The rotational momentum may be due not only to the Coulomb repulsion of the stubs of the fragments in the case when the neck of the fissioning nucleus is asymmetrically broken relative to the fission axis [1], but also as a result of the general spherical asymmetry of the fragment situated in the Coulomb field of another fragment. The fragment rotational energy obtained in this case goes over in final analysis into radiation energy (prompt neutrons and gamma quanta).

The scatter in the kinetic energy of the fragments is due principally to differences in their shapes at the instant of fission. The differences in the fragment shapes lead both to fluctuations of the average distance between them and to fluctuations of their rotational momentum. If the fluctuations in the distance between fragments at the instant of fission give the scatter of the value of the translational energy of the fragments, the differences in the values of the rotational momentum lead to a scatter in their rotational energy. For one and the same Coulomb-interaction energy between fragments and for the same distances between them at the instant of fission, the kinetic energy of the fragments will depend on what part of the Coulomb-interaction energy has gone to create the rotational motion of the fragments, that is, it will depend on the shape of the latter. In this case the fluctuations of the kinetic energy of the fragments (ΔE_{kin}) will be due to fluctuations in their rotational energy (ΔE_{rot}). In the more general case ΔE_{kin} is due both to fluctuations in the distance between the fragments and to fluctuations in the rotational momentum of these fragments.

The experimentally measured width of the distribution of the total kinetic energy of the fragments includes also the scatter due to the recoil of the neutrons as they evaporate from the fragments and the scatter due to the oscillations in the value of the fragment charge. These sources of scatter are not, however, fundamental [2], since the half-width of the distribution in the kinetic energy of the fragments, due to the neutron recoil (ΔE_n) is approximately 5 MeV, while the half width due to the fluctuations in the fragment charge (ΔE_Z) amounts to approximately 3 MeV.

Thus, the distribution width of the total kinetic energy of the fragments at half the maximum value is determined by the relation

$$\Delta E_{\text{kin}} = [(\Delta E_\rho)^2 + (\Delta E_{\text{rot}})^2 + (\Delta E_n)^2 + (\Delta E_Z)^2]^{1/2} \approx 20 \text{ MeV}, \quad (1)$$

where ΔE_ρ is the scatter in the fragment kinetic energy, due to the fluctuations of the average distance between them at the instant of fission.

Starting from the data available at the present time, we can estimate the contribution made to the variance of the kinetic energy of the fragments by the fluctuations of their rotational energy. The rotational energy of both fragments is $E_{rot} = \hbar^2 j^2/J$, where j is the average rotational momentum of the fragments; $J = {}^2\!/_5 mAR^2$ is the moment of inertia; A is the atomic number; R is the radius of the fragment; and m is the mass of the nucleon. The fluctuations of the rotational energy $\Delta E_{rot} = 2\hbar^2 J^{-1} j \Delta j$ are calculated if one knows the magnitude and the scatter of the rotational momentum.

For rotating nuclei, as shown by Strutinskiĭ [3], neutron metastable states can exist, when the deexcitation cannot proceed via neutron evaporation, even if the excitation of the nucleus is larger than the neutron binding energy. In this case the emission of a cascade of gamma quanta which carry away the excess momentum is more probable.

Calculations by Pik-Pichak [4] have shown that for nuclei with large angular momentum the average gamma-radiation energy (E_γ) emitted after the evaporation of the neutrons is determined by the relation $E_\gamma = E_{rot} - B_n/2$, where B_n is the binding energy of the neutron. Using the experimental value of the gamma-ray energy emitted by the fragment, $E_\gamma = 3.6$ MeV [6] (for one fragment) and taking $B_n = 5.4$ MeV [6], we obtain $j \approx 25$ for $A = 115$.

The value of the rotational momentum obtained from the relation $E_\gamma \approx E_{rot} - B_n/2$, which holds true for nuclei with low temperature, agrees with the value of the rotational momentum obtained from an investigation of the angular anisotropy of the prompt gamma radiation in the fission of U^{235} by thermal neutrons [7].

The fluctuations in the value of the rotational momentum (Δj) are determined by the mechanism of formation of this momentum. At the present time the character of the distribution of the values of the rotational momentum is not known. Recognizing, however, that the fragments have a high atomic number and that their initial excitation is large, we can apparently assume a Gaussian distribution for the rotational momentum, with variance $\sigma^2 = JT/\hbar^2$ [8], where T is the fragment temperature.

The mean square deviation of the rotational momentum from the most probable value is in this case $\sigma = \sqrt{JT}/\hbar = 5.8$ for $T = 0.6$ MeV. The width of the distribution of the rotational momentum at half its height is then $\Delta j = 2.3$; $\sigma = 13.3$. Knowing j and Δj we obtain $\Delta E_{rot} \approx 12$ MeV.

From relation (1) we can estimate the contribution made to the scatter of the fragment kinetic energy by the fluctuations in the distance between them at the instant of fission. It turns out to be approximately 15 MeV.

The obtained values of ΔE_{rot} and ΔE_ρ show that the dispersion of the total kinetic energy of the fragments is due approximately in equal degree to both fluctuations in the rotational energy of the fragments and fluctuations in the average distance between them at the instant of fission.

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