COLLINEAR TRIPARTITION OF HIGHLY EXCITED ^{238}U NUCLEI

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Experiments on fission of heavy nuclei were performed at proton beams with energies in the range of 0.46–9 GeV using photoemulsion layers and the two-arm SAVEC (Spectrometer of Angle-Velocity-Energy Correlation) arrangement [1, 2]. It was found that the fission process of highly excited heavy nuclei had competed with conventional fission after the cascade-evaporation stage of the reaction. This process is a tripartition of a heavy nucleus with highly excited central part in the space between two massive fission fragments. All three fragments are moving in collinear geometry, the nuclear-unstable central fragment disintegrating at the stage of the Coulomb repulsion. The tripartition process was observed in ^{238}U, ^{197}Au and ^{184}W target nuclei at 1 GeV proton beam. The low energy fission process was detected simultaneously in the same experiment but with ^{238}U target nuclei only. Schematic comparison of low and high energy fission configurations for ^{238}U target nuclei is made in Fig.1. Unlike the low energy fission the high energy fission configuration maintains a noticeable charge Z_3 in the space between two arising fragments with charges Z_1 and Z_2. All the experimental observations [3] are in agreement with collinear three-body kinematics:

1. collinear geometry of the detection of two massive fission fragments;
2. large nucleon losses determined as a missing mass for two massive fragments $\Delta M = A_o - (M_1 + M_2)$;
3. momentum disbalance of two collinear moving detectable massive fragments;
4. enhanced total kinetic energy of two massive fragments for large nucleon losses;
5. missing mass collinear velocity dependence on ΔM value.

One of the most important characteristics of any fission process is the primordial distance D between detected massive fragments which can be determined according to the equality of total kinetic and potential energies

$$E_{tot} = U_{Coulomb}.$$

In the case of two-body kinematics it is reduced to

$$E_{tot} = \frac{e^2 Z_1 \cdot Z_2}{D_2},$$

where $E_{tot} = E_1 + E_2$. For collinear tripartition this equation should be changed

$$E_{tot} = \frac{e^2[Z_1 \cdot Z_2 + 2Z_3(Z_1 + Z_2)]}{D_3},$$

where $E_{tot} = E_1 + E_2 + E_3$, and Z_3 is the central body charge. As usual E_3 is much smaller than E_1 or E_2.

Symmetric and asymmetric mass splits are distinguished in the low energy fission. It is quite possible to use the measured energy ratio E_1/E_2 as a mass M_2/M_1 or charge Z_2/Z_1 ratio for symmetric and asymmetric mass splits. It is not the case for the collinear tripartition of highly excited ^{238}U nuclei. Comparison was made of experimental data on many-body

breakup of ^{238}U nuclei in the nuclear emulsion layers and those on nucleon losses measured with the SAVEC-arrangement at the 1 GeV proton beam [1]. The most probable number 8 ± 1 of charged particles was found to correspond to large nucleon losses. Almost all the charged particles accompanying massive complementary fragments had charges no more than two. Single-charged particles were detected twice as often as double-charged ones. It means that the most probable value 12 for Z_3 may be chosen. Accordingly charges $Z_1 = Z_2 = 40$ were also chosen for external tripartition fragments. However combination $Z_3 = 18$, $Z_1 = Z_2 = 37$ is also possible. The Table contains measured kinetic energies, adopted values for fragment charges and evaluated distances D_2 and D_3. By letters a and s are denoted mass-asymmetric and mass-symmetric fission processes.

Table

	Low energy fission				Collinear tripartition					
	$E_1 + E_2$, MeV	Z_1	Z_2	D_2, fm	$E_1 + E_2$, MeV	E_3, MeV	Z_1	Z_2	Z_3	D_3, fm
a	176 ± 2	51	41	17.1			40	40	12	35
s	166 ± 2	46	46	18.4	136 ± 3	9 ± 0.3	37	37	18	40

It is clear that the noticeable difference in D_2 for symmetric and asymmetric fissions is almost negligible in comparison of D_3 with D_2. Twice as large deformation of the primordial configuration is inherent for the highly excited fissioning nucleus of ^{238}U.

Collinearity of the tripartition process may be ensured by particle ejection in cascade collisions of the incident proton with nucleons of the target nucleus. It is required to compensate the incident proton linear momentum. Fig.2 shows the calculated energy deposit to a fissioning nucleus at the ejection of variable numbers n of nucleons in the direction of incident protons with energies 0.46, 0.66 and 1 GeV. Secondary ejected particles compensate the linear momentum, residual target nuclei being excited up to hundreds of MeVs. For example two ejectiles at the 1-GeV proton interaction will leave a target nucleus with excitation at the level of 344 MeV. The same excitation can be reached by 0.46-GeV proton interaction only for five ejectiles which may occur with much lower probability. This kinematical circumstance almost completely clarifies the energy dependence of the collinear tripartition probability in the range of 0.46-9 GeV [2].

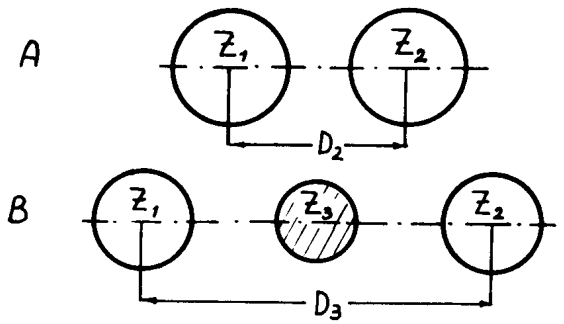

Fig.1. Primordial configurations: A — low energy fission, B — high energy collinear tripartition. Hatched sphere — highly excited nuclear matter in the space between two massive detectable fragments

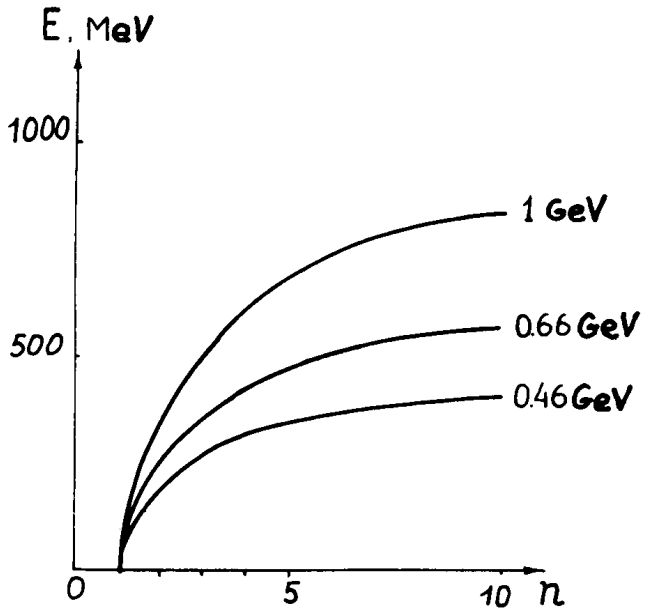

Fig.2. Dependence of the excitation energy of fissioning nuclei on the number n of ejected nucleons compensating incident proton linear momentum at 0.46, 0.66 and 1 GeV

REFERENCES

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