THE SIGNATURE FOR PROMPT MULTIFRAGMENTATION*

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Following the idea of López and Randrup (*Nucl. Phys.* **A491**, 477 (1989)) the influence of the Coulomb interaction on trajectories of particles emitted from a hot nuclear system is investigated. It is found that the Coulomb field of the two heaviest fragments focuses velocities of the other intermediate mass fragments when the hot system breaks up simultaneously, while in the case of the sequential binary decay these velocities exhibit a nearly isotropic distribution.

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Nuclear systems created in nuclear collisions, at sufficiently high energy, are expected to decay by multifragmentation [2]. Such processes has been foreseen *e.g.*by the equation of state of nuclear matter, as a liquid–vapour phase transition [3]. They were also suggested by models based on the statistical [4], percolation [5], dynamical mean field [6] or molecular dynamics [7] approximations.

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Verification of the multifragmentation models by comparison with experimental data is alas difficult and frequently impossible. This is so because experiments cannot simply distinguish prompt multifragmentation (PM) from a sequential break up (a chain of sequential binary decays (SBD)). Recently López and Randrup [1] suggested that these two processes should exhibit a kinematic difference, which could be found by studying the Coulomb trajectories of decay fragments in the early stage of the disintegration process. They have found some encouraging differences in the proton energy spectra, velocity distributions, and velocity correlations. However, these differences seem to be too small to make a clear distinction between the PM and SBD processes possible, unless both the experimental accuracy and our understanding of the multifragmentation improves considerably.

In this work we follow the idea of López and Randrup [1], but we concentrate our attention on trajectories of particles with $A > 1$, moving in the Coulomb field created by the two heaviest fragments. We seek here a focusing effect similarly as in ternary fission [8]. All the calculations presented were performed for the $^{150}_{62}$Sm hot nucleus in the CM system, and are based on an assumption of existence of a compound system. No entrance channel effects were considered.

We begin with a hot system created in some unspecified way, with the initial excitation energy $E_0^*/A_0 = 5$ MeV/A. It may disassemble promptly or sequentially. For each disintegration event it is assumed that the final mass (charge) spectrum of the fragments as well as the final total kinetic energy are the same for the PM and SBD alternatives [1, 9, 10]. Therefore, in both cases the SBD Monte Carlo code BINFRA [11] is used to calculate the mass (charge) partition of fragments. It also provides the value of the final total kinetic energy of fragments. Now one calculates trajectories of PM particles confined just after multifragmentation in some initial "freeze-out volume" and accelerated next in the Coulomb field of other participants. The particles can be excited and are allowed to deexcite by sequential binary decay. At some effectively infinite distance from the initial hot system one can compare the velocity distributions of PM fragments with those calculated for the sequential decay (the SBD Monte Carlo code).

The initial "freeze-out volume" is represented by the volume of a sphere in which all the fragments can be enclosed. It is determined by randomly sampling positions of excited fragments and shifting them in such a way as to produce the minimum possible non overlapping spherical configuration. The above procedure should conserve energy and momentum ($\widehat{P} = 0$) of the system. We assume that the initial hot nucleus was created in the central collision and consequently its angular momentum should be close to zero. The formation of the initial "freeze-out volume" and the numerical integration of the equations of motion of fragments is performed by the code

MULFRA. The most probable value of the "freeze-out volume" calculated by MULFRA is about three times the volume of the initial hot nucleus. It depends slightly on the partition of the initial system. One can get the "freeze-out volume" which is only about twice the initial volume, when the packing procedure begins from the two heaviest fragments. Our calculations show that the final result is not sensitive to its exact value.

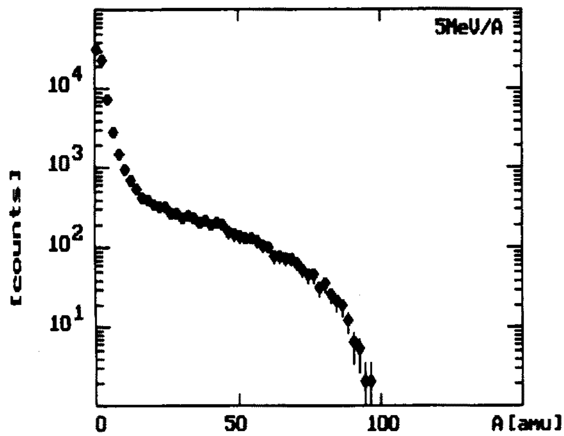

Fig. 1. Mass distribution of fragments for the initial excitation energy of the Sm nucleus 5MeV/A. 5 000 events.

Fig. 1 shows the mass spectrum of fragments, provided by the SBD code. As one can see, at the excitation energy in question (5 MeV/A), the emission of intermediate mass fragments prevails. We now concentrate attention on the two heaviest fragments in each event, and on trajectories of particles heavier than protons. The two heaviest fragments remove, on average, 50% of the total charge. Partition of the charge between the first and the second fragment displays a rather broad distribution. The energy spectrum (sum of kinetic energies) of the two heaviest fragments is broad, and for the sequential decay shifted towards lower energies. It indicates a pre-scission emission of charge in some of the SBD events. The average angle between the two heaviest fragments is smaller then 180°, both for the multifragment and binary breakup. This suggests a mechanism which perturbs the back to back push. It can be associated with the secondary evaporation of light particles after the sequential binary fission, and with the Coulomb acceleration from the rest of charged fragments executed during the simultaneous multifragmentation.

As one can see the two heaviest fragments participating in disintegration take a large part of the charge of the system. They are emitted almost back to back, and at the beginning should create an axial, very strong Coulomb field. It is interesting to look for possible effects induced by the field on other charged fragments ($A > 1$).

As the CM frame has a rotational degeneracy we propose a coordinate system with the v_x axis given by the vector $\hat{v}_1 - \hat{v}_2$. Here $\hat{v}_1$ and $\hat{v}_2$ is the velocity of the heaviest, and of the second heaviest fragment, respectively. This means that for each event we are performing a rotation of the coordinate system to emphasize the axial symmetry of the Coulomb field, of the two heaviest fragments. Fig. 2 shows, for fragments $A > 1$, angular distribution of the velocity vectors $dN(\theta)/d\Omega$ presented in the coordinate system which is defined event by event. Here θ is an angle between the v_x axis and the velocity vector, and N is a number of vectors in the velocity space. As one can see, the PM velocity distribution is represented in Fig. 2 by a Gaussian like curve, while the SBD one is a horizontal line. It suggests a focusing effect caused by the Coulomb field of the two heaviest fragments. The intensity of the Coulomb field drops too quickly to make possible for the SBD particles, coming from the much slower evaporation process, to be focused. The calculations show a much weaker effect for protons. Probably they leave the region of the strong field to early. Generally, the focusing is stronger for heavier ejectiles (intermediate mass fragments).

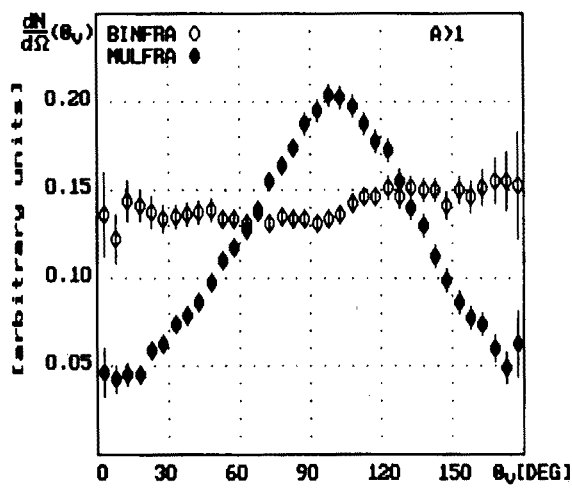

Fig. 2. Angular distribution of the fragment velocity vectors ($A > 1$), as predicted for the binary decay (BINFRA code), and for the prompt multifragmentation (MULFRA code). 5 000 events.

The focusing effect depends also on the excitation of the initial system. It is the strongest for the 2 MeV/A initial excitation, it decreases for 5 MeV/A, and is almost absent for 10 MeV/A.

For all calculations presented above the initial excitation of fragments just after prompt multifragmentation was assumed to be $E_F^*/A_F=\frac{2}{10}E_0^*/A_0$. It was found that the focusing begins to deteriorate for $E_F^*/A_F=\frac{6}{10}E_0^*/A_0$, and at $E_F^*/A_F=\frac{8}{10}E_0^*/A_0$ is less strong.

As seen from Fig. 2 the Coulomb focusing offers a possibility to be used as a signature of prompt multifragmentation. In an eventual experiment, a coincidence between the two heaviest fragments should serve as a trigger. As a second trigger one should use *e.g.*the high multiplicity of particles [12] in order to select central collisions. The system has then small or zero angular momentum, and does not rotate. A rotation of the system ($L > 0$), will smear the PM focusing effects to be observed in the reaction plane. Some focusing should be, however, seen around the direction perpendicular to the reaction plane, where one does not expect emission from the sequential decay. One should be aware that such experiments will be rather difficult. We need velocity measurements, the 4π geometry, and a low threshold detection and identification of heavy fragments.

A more comprehensive discussion of the method, and full presentation of results will be published.

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