Statistical evolution of fragment isospin in nuclear multifragmentation.

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The knowledge of the isotope composition of fragments produced in nuclear multifragmentation can help in resolving important problems: Do the fragments keep the memory of the initial dynamical stage or are they produced statistically? How does the isospin influence the disintegration of finite nuclei and what is the difference to the case of nuclear matter? What is the isospin dependence of the nuclear equation of state? Generally, this study addresses an intriguing interdisciplinary problem of the phase transition in a finite-size two-component system (i.e. in a nucleus consisting of neutrons and protons), that is instructive for all fields dealing with finite systems. The problem was investigated within the statistical multifragmentation model (SMM) [1], which is successfully used for explanation of experimental data. A new Markov chain method of partition generation was incorporated in the model [2], that allows for considering the multifragmentation process on a solid microcanonical basis. The reported results reflect statistical properties of the fragment production and can be used for identification of the phenomenon.

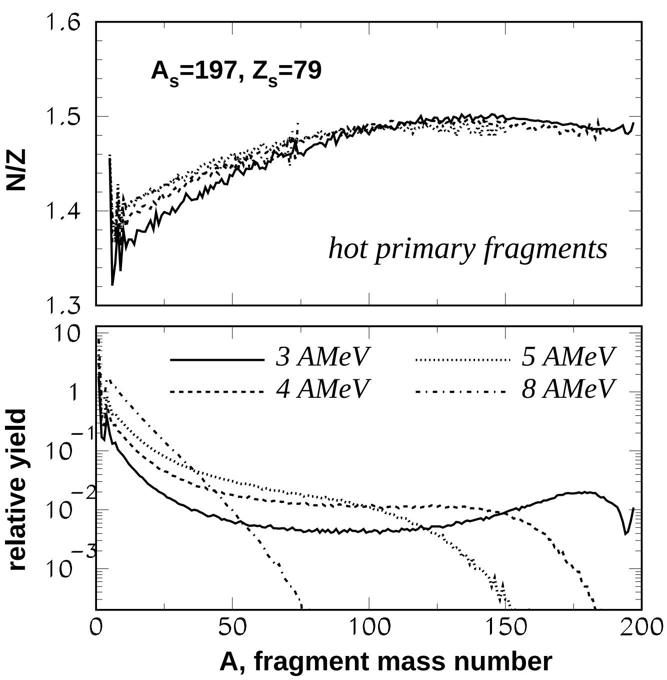

Figure 1: The neutron-to-proton ratio N/Z (top) and relative yield (bottom) of hot primary fragments produced after break-up of Au nuclei at different excitation energies: 3 (solid lines), 4 (dashed lines), 5 (dotted lines) and 8 (dot-dashed lines) MeV per nucleon.

The mass distributions and neutron-to-proton ratios (N/Z) of hot primary fragments produced after multifragmentation of a Au source (mass number A_s=197, charge Z_s=79) are shown in Fig. 1. One can see a general statistical trend: the N/Z ratio of the fragments increases with their mass numbers. This is a consequence of the interplay between the Coulomb and symmetry energy contributions to the binding energy of fragments [1]. This trend persists up to $A \leq A_s/2$, while at larger A the finite-size effects due to the mass and charge conservation prevail. In Fig. 1 one can also see the evolution of the N/Z ratio in the excitation energy range E_s^*=3–8 MeV/nucleon, where the fragment mass distribution evolves from the U–shape, at the multifragmentation threshold $E_s^* \sim 3$ MeV/nucleon, to an exponential fall at the highest energy. This energy range is usually associated with a liquid-gas type phase transition in finite nuclei: During this evolution the temperature reaches a "plateau" and is nearly constant [1, 3]. As the energy increases the N/Z ratio of primary intermediate mass fragments (IMF, charges Z=3–20) increases, too. The reason is that the heaviest neutron-rich fragments are destroyed at increasing excitation energy, and some of their neutrons are bound in the IMFs, since the number of free neutrons is still small at this stage. Simultaneously, the N/Z ratio of the heaviest fragments decreases slightly. At very high excitation energy ($E_s^* > 8$ MeV/nucleon) the N/Z ratio of IMFs does not rise anymore but drops because no heavier fragments are left and the number of free neutrons increases rapidly, together with the temperature. This isospin evolution shows how the isospin fractionation phenomenon predicted for nuclear matter [4] actually shows up in finite nuclear systems. Such a mechanism is consistent with recent experimental data [5]. New experiments for studying mass and isospin effects in multifragmentation are planned at GSI [6].

Interesting phenomena are also predicted for peripheral nucleus–nucleus collisions [2]: 1) The neutron content of IMF increases if a considerable angular momentum is transfered to the source, because of an interplay of the rotational and Coulomb energy. 2) There is a break of the symmetry of the phase space population, including the space isospin distribution, because of the external Coulomb field of the partner nucleus. The space asymmetry leads to predominant population of the midrapidity kinematic region by neutron-rich IMFs, that should be considered as purely statistical alternative to a dynamical explanation of the midrapidity emission [7]. Such processes are examples of a new kind of statistical emission influenced by an inhomogeneous long–range field.

References

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