Symmetry energy of fragments produced in multifragmentation

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In recent years, interest in the isospin degree of freedom of reaction products has considerably increased, motivated by the possibility of extracting information on the symmetry energy of hot nuclei and nuclear matter during the liquid–gas phase transition. It has been shown that the yield ratio of a given isotope produced in two reactions with different isospin asymmetries exhibits an exponential dependence on *Z* and *N*, an observation known as isoscaling [1]. Based on the statistical interpretation of isoscaling, the coefficient of the symmetry term in the nuclear mass can be extracted [2].

In this work (see [3]) we present the analysis of fragments in the charge range Z=10–13, which may be associated with multifragmentation at high excitation energy and subnuclear density, produced in the reactions of ^{136}Xe+Pb and ^{124}Xe+Pb at 1 *A* GeV. We combine the isoscaling analysis with the experimentally determined *N/Z* [4] of the final residues to investigate the symmetry energy of hot primary fragments. As a basis for our study we take the SMM model [5].

The isoscaling analysis is based on the production ratios R_{21} of fragments with a given *N* and *Z* in reactions with different isospin asymmetries:

$$R_{21} \propto \exp(\alpha \cdot N + \beta \cdot Z)\,, \tag{1}$$

where α and β are parameters.

Within the statistical approach, the isoscaling parameter α is shown to depend only on the coefficient γ of the symmetry term, on the temperature and on the isotopic composition of the sources:

$$\alpha \approx 4 \cdot \frac{\gamma}{T} \cdot \left(\frac{Z_1^2}{A_1^2} - \frac{Z_2^2}{A_2^2}\right) \tag{2}$$

With the use of relation (2), the symmetry term may be extracted from α, provided T and the *N/Z* of the sources are known. Using above equations, from the experimental data presented in [4] we have obtained [3] an ‘apparent’ $\gamma_{ap} \approx 14 \pm 3$ MeV, that is essentially lower than the value of $\gamma = 25$ MeV. In the statistical approach, the formula (2) was obtained for the freeze-out conditions. In order to establish the connection between γ of the hot fragments and γ_{ap} obtained from observed cold fragments we made corrections for the secondary de-excitation (see [3]). Fig. 2 shows the calculated γ dependence on α extracted from the hot primary fragments in the freeze-out volume, and for the cold fragments after the secondary de-excitation. We show the two kinds of evaporation calculations: one is performed without considering evolution of symmetry energy during evaporation and the other one (new model), which includes this evolution. The new model predicts the final values of α much closer to the initial ones at smaller γ. The experimentally determined value of α can be reproduced only by lower values of the γ coefficient, e.g. $\gamma \approx$ 5–8 MeV and 11–12 MeV with the old and new evaporation calculation, respectively.

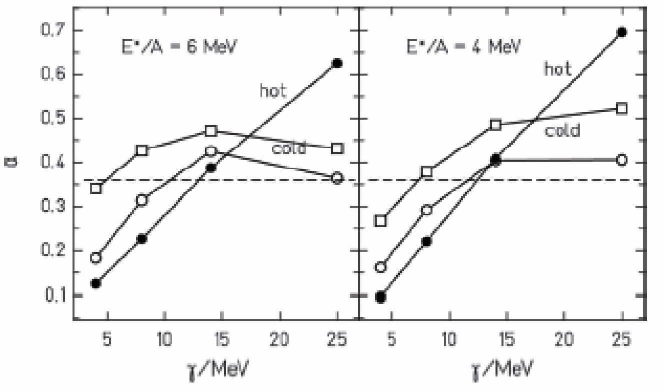

Figure 2: The isoscaling parameter α versus γ obtained in SMM calculations for ^{136}Xe and ^{124}Xe sources, and with the excitation energies 6 *A* MeV (left panel) and 4 *A* MeV (right panel). The solid symbols represent primary hot fragments, empty symbols show final cold fragments; the new evaporation model (open circles), the old evaporation model (open squares). The dashed line represents α extracted from the experimental data. For more details, see [3].

We have also used the *N/Z* ratio to investigate γ and obtained consistent results, see [3]. The coincidence of both methods makes us more confident about the decrease of the symmetry energy of hot light fragments. Our result shows that the properties of light nuclei can change during the nuclear liquid–gas phase transition. With the multifragmentation reaction one can investigate hot nuclei produced at the temperatures around T=3–8 MeV and at the densities of the matter around ρ = (0.1–0.3) ρ_0. As was demonstrated in [6], the decrease of the symmetry energy in hot fragments may have important consequences for supernova processes, where densities and temperatures close to the nuclear multifragmentation case can be reached.

References

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