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Fragment Composition in Central Heavy-Ion Collisions

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Abstract

Charge, mass and isotopic distributions of fragments formed in the central collisions of neutron poor and neutron rich elements 112Sn + 112Sn and 124Sn + 124Sn have been theoretically calculated and compared to the experimental data. Influence of surface and symmetry terms on charge and isotopic distributions, at low density freeze-out were investigated. We show that significant reduction of the symmetry term coefficient leads to better reproduction of the isotopic distributions, while the surface term effect is negligible. This is in agreement with our previous findings obtained from the interpretation of both central and peripheral heavy ion collisions.

Keywords: central collisions, fragment yield, multifragmentation, symmetry energy.

1. INTRODUCTION

When two heavy-ion collide, a compressed and hot blob of nuclear matter is formed. We assume that this dense and hot matter will expand as a result of repulsive nucleon-nucleon forces and enter a low density freeze-out region where the system reaches a statistical equilibrium. In this stage the matter becomes unstable to liquid-gas phase transitions (nuclear fragments are considered as liquid droplets). In the present study, we studied to reproduce the experimental data measured at the National Superconducting Cyclotron Laboratory at MSU [1,2], for central collisions 124,112Sn + 112,124Sn at 50 MeV/nucleon projectile energies, on the basis of the statistical multifragmentation model (SMM) [3,4]. In this model, it is assumed that a statistical equilibrium is reached at low density freeze-out region. It is also assumed that all breakup channels are composed of nucleons, and the laws of conservation of energy, momentum, angular momentum, mass number A and charge number Z are considered. Besides the breakup channels, the compound-nucleus channels at low excitations are also included, and competition between all channels is permitted. In this way, the SMM covers the conventional evaporation and fission processes occurring at low excitation energy as well as the transition region between the low and high energy de-excitation regimes. In the thermodynamic limit, SMM is consistent with liquid-gas phase transition when the liquid phase is represented by infinite nuclear cluster. In this short presentation, we do not aim to give the details of SMM, instead we refer the reader to Refs. [3-6].

2. COMPARISON WITH DATA

For our calculations, we consider two different sources neutron-rich and neutron-poor systems ^{124}Sn and ^{112}Sn, with their proton to neutron ratios N/Z =1.48 and 1.24, respectively, to see how isospin effects the multifragmentation picture.

We assume that the single source A_0=186, Z_0=75 is formed during the central collision of ^{124}Sn+^{124}Sn and A_0=168, Z_0=75 is formed during the central collision of ^{112}Sn+^{112}Sn. Calculations of the mass distribution for excited primary hot and secondary cold fragments are shown in FIG. 1. As can be seen from this figure, there are significant differences between primary and final mass yields. This is because after the deexcitation of heavier fragments formed in the multifragmentation of hot sources the smaller fragments are formed and, consequently the distributions shift to lower masses. Also a large increase in the hydrogen and helium particles are seen, since these are the main products of the decay of the heavy fragments.

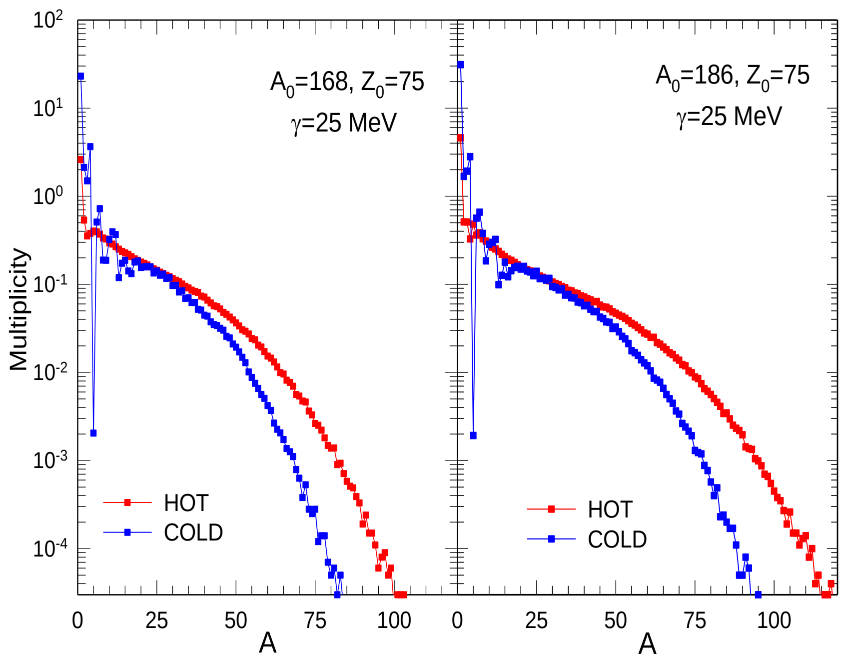

FIG. 1. Predicted mass distributions for all fragments emitted from the multifragmentation of the sources with A0=168, Z0=75 assumed to be formed in central collisions ^{112}Sn + ^{112}Sn (left panel) and with A0=186, Z0=75 to be formed in ^{124}Sn + ^{124}Sn (right panel) for the primary hot (red symbols) and secondary cold fragments (blue symbols).

In FIG. 2. we also show the results for theoretically predicted mass distributions for light fragments with A ≤20 from the multifragmentation of the sources with A0 = 168 and Z0 = 75 and A0 =186 and Z0 =75. The dashed lines are the predicted primary yields and the solid lines are predicted yields after secondary decay. The data from the multifragmentation of central collisions of ^{112}Sn + ^{112}Sn are shown as open symbols (left panel) and closed circles for ^{124}Sn + ^{124}Sn reaction (right panel). For comparisons with experimental data, the differential multiplicities for various masses with A ≤20 are plotted in Fig.2, too. It is seen that the present calculations have reproduced many features of the mass distribution. Here, we also point out that we have tried the effect of symmetry energy to the mass and charge yield by taking different values of gamma into acounts, and it was seen that the effect of variation of symmetry energy to the yields is negligible (see for example Refs. [4-6]).
In FIG.3. we compare the predicted isotopic yields of cold fragments with the data for carbon and oxygen isotopes for the symmetry term value at γ = 14 MeV. It is seen from these figure that our secondary cold fragment distributions compare well with the experimental data at the reduced gamma value γ = 14 MeV.

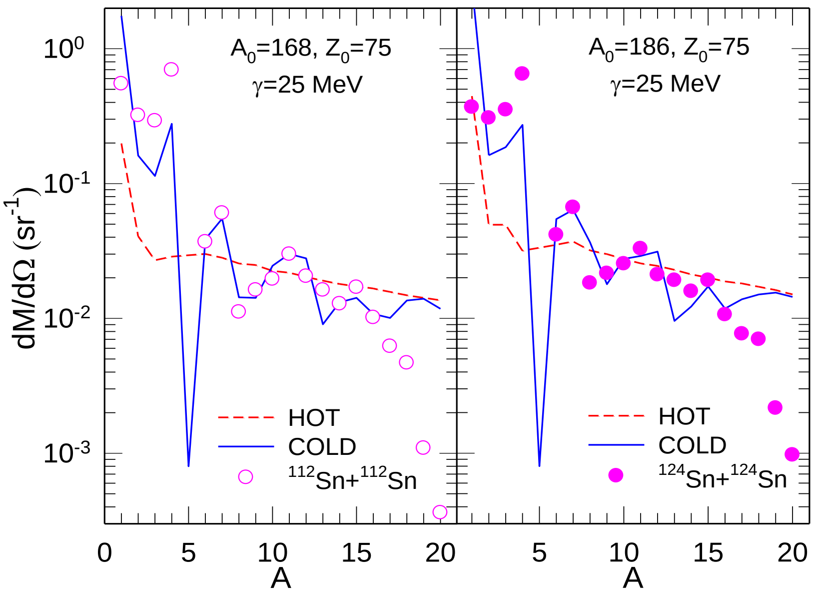

FIG. 2. Experimental and predicted mass distributions for lighter fragments with A ≤20 emitted from the multifragmentation of the sources with A0=168, Z0=75 assumed to be formed in central collisions ^{112}Sn + ^{112}Sn (left panel) and with A0=186, Z0=75 formed in central collisions ^{124}Sn + ^{124}Sn (right panel) for the primary hot (red dashed lines) and cold fragments (blue solid lines). Empty and solid circles show the experimental data, respectively.

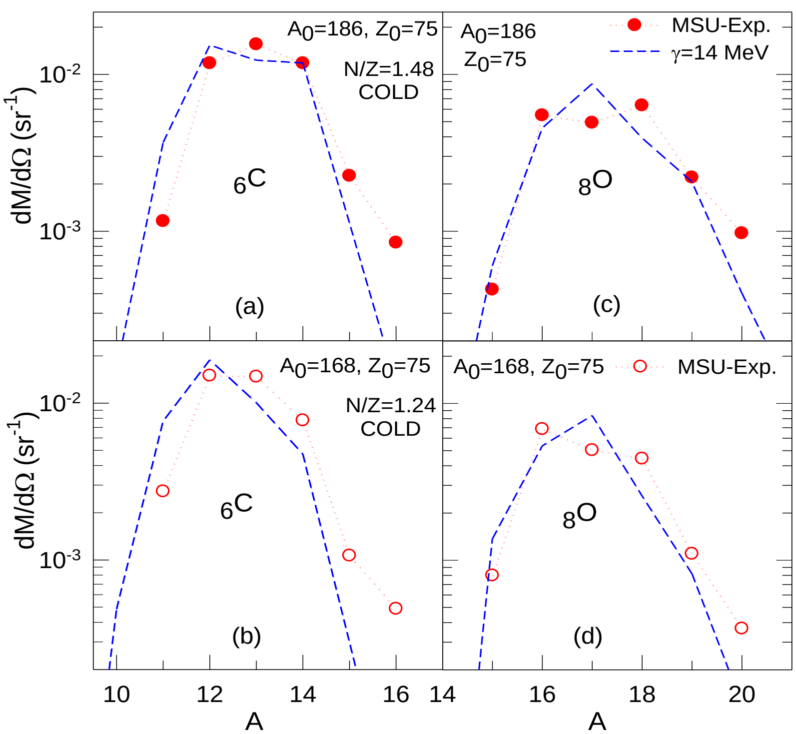

FIG. 3. Predicted isotope distributions for carbon and oxygen fragments for the both sources. Solid red symbols show experimental values for oxygen and empty symbols for carbon (Ref. [6]).

3. CONCLUSIONS

The comparisons of SMM predictions with the MSU experimental data show that one can reproduce charge, isotope and mass characteristics of the multifragmentation products measured in central collisions with different isospin content, on the basis of SMM. To reproduce the MSU data for isotopic yields, symmetry energy term is significantly reduced to somewhere around 14 MeV. However, symmetry energy has no influence on mass and charge distributions which are rather effected by the surface energy, since production of new fragments means increasing the surface contribution to the total energy of the system. Therefore, even small variations of the surface energy lead to big changes of fragment mass and charge distributions [4-9]. This kind of analyses and obtained information are expected to be useful in investigating the astrophysical processes such as type II-supernova explosions and modelling of neutron star crusts.

4. ACKNOWLEDGEMENTS

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