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Isotopic Yields in Peripheral Heavy-Ion Collisions

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Abstract

We have calculated production cross sections and isotopic distributions of the projectile fragments emerging from the reactions 112,124Sn + 112,124Sn at 50 MeV/nucleon incident beam energy, performed at the cyclotron of Michigan State University (MSU). For the interpretation of the data, we carried out the calculations within the statistical multifragmentation model (SMM). The possible modification of symmetry energy parameter, in the multifragmentation region at the low density freeze-out has been studied. It is shown that a significant reduction of the symmetry energy term is found necessary to reproduce experimental data. The results are in agreement with recent findings.

Keywords: isotopic yield, multifragmentation, projectile fragments, symmetry energy.

1. INTRODUCTION

The results of theoretical simulations to reproduce the experimental data are important not only for the context of nuclear physics but also for astrophysical processes such as supernova explosions and formation of neutron stars. In the present study, we introduce the theoretical simulation of peripheral collisions 112,124Sn + 112,124Sn at 50 MeV/nucleon projectile energies, measured at the National Superconducting Cyclotron Laboratory at MSU [1], with different projectile and target configurations in terms of neutron to proton ratios, on the basis of a statistical approach. The experimental values of isotopic yields were measured at impact parameter gate b/bmax > 0.8 for peripheral collisions. The possible in-medium modification of symmetry energy parameter can be studied by means of isotopic curves, isoscaling and N/Z analyses, on the basis of SMM [2]. In this short communication we shall concentrate on the reproduction of isotopic curves by comparison with experimental data. For details of the other approaches in this line, we refer the readers to Refs. [3-6].

2. CALCULATIONS AND COMPARISON WITH EXPERIMENTAL DATA

Theoretical simulations for the reaction analyses have been carried out according to SMM. According to the SMM, the breakup channels are generated by Monte Carlo method according to their weights, and the system should obey laws of conservation of energy E*, mass number A and charge number Z. The statistical weight of a breakup channels is defined by

$$W_j = \xi \exp \left(\mathrm{S}_{\mathrm{j}} \left(E^*, A, Z \right) \right). \tag{1}$$

where ξ is the normalization constant, Sj the entropy of each channel, E* the excitation energy, A the mass number, and Z the charge number of the fragments. SMM includes all breakup channels which are composed of nucleons and excited fragments. Besides the breakup channels, the compound-nucleus channels at low excitations are also included, and competition between all channels is permitted so that the SMM covers the conventional evaporation and fission processes occurring at low excitation energy as well. Light fragments with mass number A ≤ 4 and charge number Z ≤ 2 are considered as elementary particles with the corresponding spins (nuclear gas). The fragments with mass number A > 4 are considered as heated nuclear liquid drops. Free energies $F_{A,Z}$ of each fragment are parameterized as a sum of the bulk, surface, Coulomb and symmetry energy contributions as follows:

$$F_{A,Z} = F^{B}_{A,Z} + F^{S}_{A,Z} + E^{C}_{A,Z} + E^{sym}_{A,Z}. \quad (2)$$

The symmetry energy is defined by $E^{sym}_{A,Z} = \gamma (A - 2Z)^2/A$, where γ = 25 MeV is the symmetry energy parameter. All of these parameters are taken from the well known Bethe–Weizsacker formula with the assumption of isolated fragments with normal density. However, their modifications in the hot and dense freeze-out configuration follow the analysis of experimental data. In the present calculations, we consider the standard SMM liquid-drop parametrization and the same normalization procedure used in our previous studies [3-6].

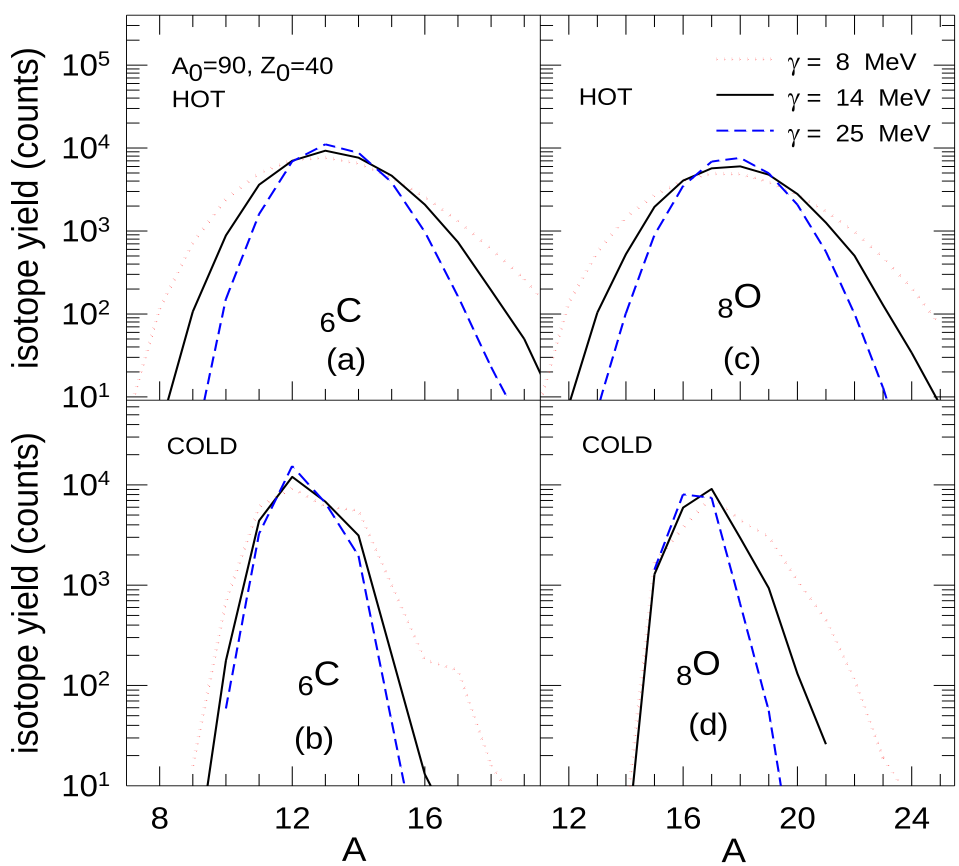

FIG. 1. Predicted isotope distributions for carbon and oxygen fragments emitted from the projectile sources with A0=90, Z0=40 (assumed to be formed in ^{112}Sn + ^{112}Sn collisions), at various values of symmetry term for the primary hot and cold fragments. The panels (a) and (c) show the primary hot fragments, and the panels (b) and (d) the secondary cold fragments for carbon and oxygen, respectively.

In FIG.1. we show the isotopic yields of hot and cold fragments for carbon and oxygen isotopes at various values of the symmetry term. It is seen from these figure that the width of the distributions is influenced by the symmetry term. Isotopic distribution widens considerably with the decreasing symmetry energy.The isotopic distributions are pushed towards the value of stability as a result of secondary de-excitations. Therefore, the primary hot fragment distributions are much wider than those of the secondary cold fragments . In this way, we can estimate the symmetry energy by comparing the predicted distributions with experimental data in FIG. 2. One can conclude from FIG. 2. that our secondary cold fragment distributions compare well with the experimental data at the reduced gamma values at γ = 14 MeV. As is seen from this figure, the experimental data can not be well reproduced with standard gamma value γ = 25 MeV (left panels).

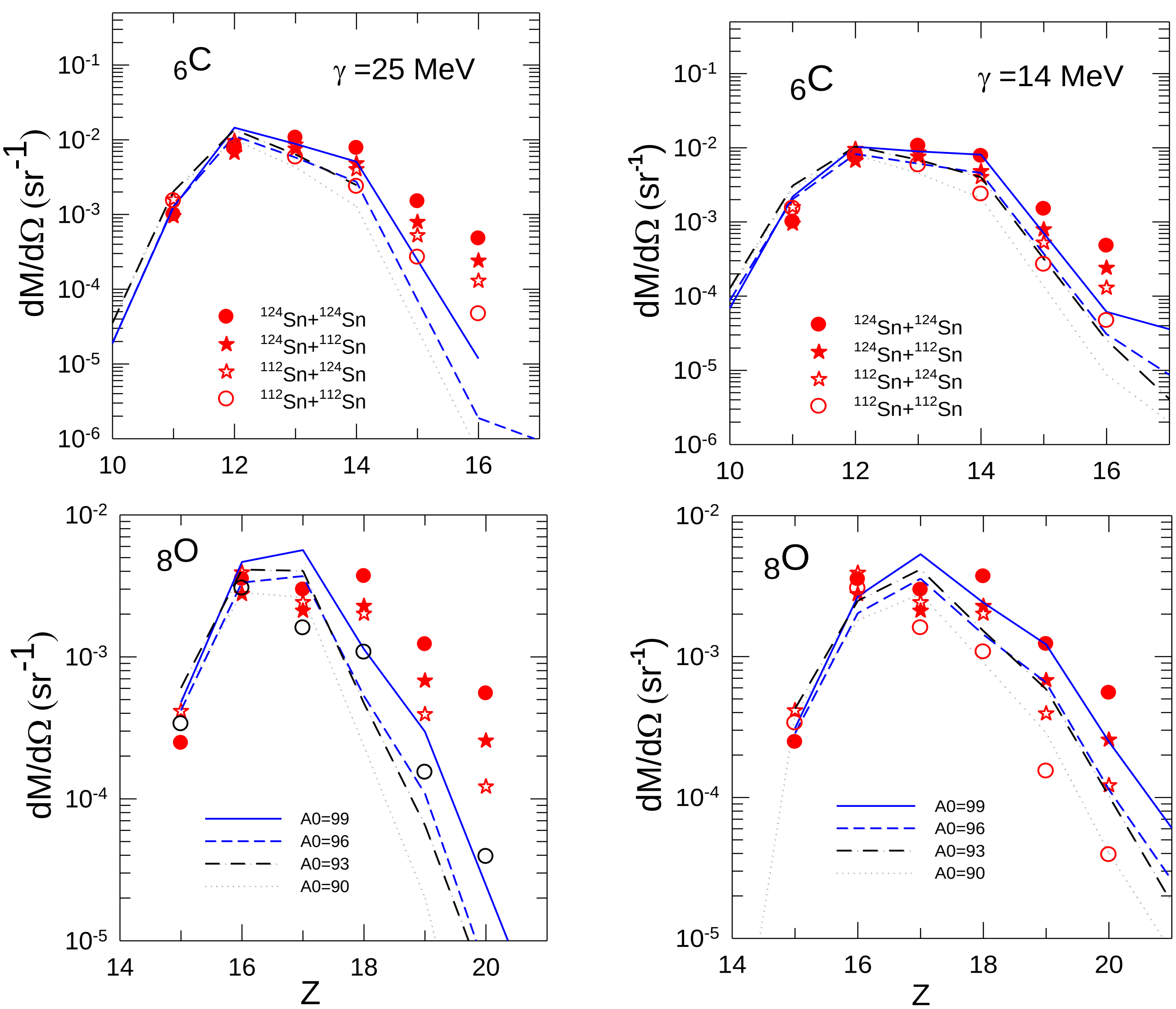

FIG. 2. Experimental and predicted isotope distributions for carbon and oxygen fragments emitted from the projectile sources with A0=99,96,93,90 Z0=40 (assumed to be formed for the reactions written in the first panel, respectively), at gamma=25 MeV (left panels) and 14 MeV (right panels).

3. CONCLUSIONS

As a result, we demonstrated that it is possible to reproduce the experimental results for the fragment isotopic yields emerging from the projectile fragmentation, within SMM on the basis of liquid-gas phase transition theory. Furthermore, it is possible to estimate the freeze-out value of the symmetry energy term through the in-medium modification by using experimental data for isotopic yields. As is seen from the figures, the symmetry energy must be reduced to the lower values to reproduce experimental isotopic curves. This is in agreement with the results in existing literature [7,8] and our previous findings [3-6].

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