Symmetry energy and isoscaling property of fragments emitted in ^{14}N, ^{20}Ne + ^{112,116,124}Sn at 18-30MeV/nucleon

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Introduction

The study of the symmetry energy term in nuclear equation of state (EOS), has been one of the most prominent research topics in nuclear astrophysics, both in the theoretical and experimental domains. It describes how the isospin content influences the binding energy of the nuclear matter. Its dependence on nucleon density determines the reaction rates of astrophysical nuclear reactions. The coefficient of symmetry energy, C_{sym}, can be measured from the isotopic compositions of the emitted fragments, through isoscaling [1]. Two reactions, 1 and 2, having the same temperature T, will exhibit isoscaling behavior if the ratio R_{21} of the yields of a particular isotope having neutron and proton number N and Z, respectively, emitted from the two reactions have an exponential relationship of the form, $R_{21}(N, Z) = Y_2(N, Z)/Y_1(N, Z) = C\ exp\ (\alpha N + \beta Z)$ (Eq. 1) where, $Y_2(N, Z)$ and $Y_1(N, Z)$, are the yields of the isotope from the neutron rich system and neutron deficient system, respectively. C is the normalisation constant, α and β are the isoscaling parameters. These two parameters are related to symmetry energy by the equation $\alpha T \approx 4C_{sym} \left[\left(\frac{Z}{A}\right)_1^2 - \left(\frac{Z}{A}\right)_2^2\right]$ (Eq. 2) and $\beta T \approx 4C_{sym} \left[\left(\frac{N}{A}\right)_1^2 - \left(\frac{N}{A}\right)_2^2\right]$ (Eq. 3) where, T is the nuclear temperature, N, Z and A are the neutron, proton and mass number of the first and second composite [1]. In this paper, we shall show the dependence of symmetry energy on excitation energy (E^*) from the study of isoscaling property of IMFs.

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Experimental details

The experiment was performed at the K500 superconducting cyclotron [2], VECC, Kolkata, using accelerated neon ion beams of energy 18 and 22 MeV/nucleon and nitrogen ion beam of energy 19 and 30 MeV/nucleon. Enriched tin isotopes, ^{112}Sn (~ 2.6 mg/ cm^2), ^{116}Sn (~2.23 mg/ cm^2) and ^{124}Sn (~ 2.81 mg/ cm^2), were used as targets. Fragments emitted in the reactions ^{20}Ne + ^{112,116,124}Sn and ^{14}N + ^{112,116,124}Sn were detected isotopically using a silicon strip ΔE - E charged particle telescope.

Results and discussion

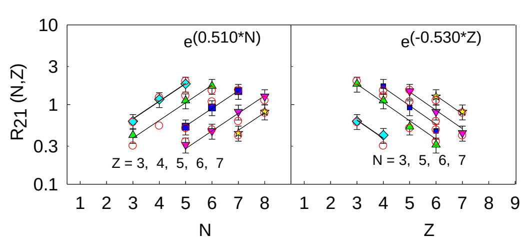

Fig. 1 The ratio of the yields of the isotopes, R_{21}, emitted from ^{14}N + ^{124}Sn and ^{14}N + ^{112}Sn, as a function of neutron number (left panel) and proton number (right panel) at beam energy 30 MeV/nucleon. All the symbols correspond experimental data and hollow circle represents the corresponding theoretical result [3].

The normalized yield ratios, R_{21} (N, Z) of different isotopes (Z = 3 - 7) emitted from the reactions N, Ne + Sn have been calculated and a typical plot is shown in Fig. 1 and fitted with Eq. 1 as shown by solid lines. It was observed that isoscaling is well respected by IMFs emitted in all reactions under present study at all excitation energies. The values of α for different systems at different excitation energy are plotted in Fig. 2(a).

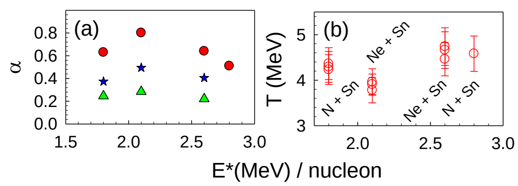

Fig. 2 Different values of (a) α {circles correspond to the Ne, N $+^{124,112}$Sn, triangles correspond to Ne, N $+^{124,116}$Sn and stars correspond to Ne, N $+^{116,112}$Sn} and (b) nuclear temperature.

The temperature has been extracted using double isotope ratio method from the yields of the isotopes, ^{6,7}Li/^{11,12}C (B = 11.57 MeV, a = 5.7) [4]. C_{sym} have been calculated using Eq. 2. A decreasing trend of C_{sym} with increasing E^*, is observed except at 1.8 MeV/nucleon as shown

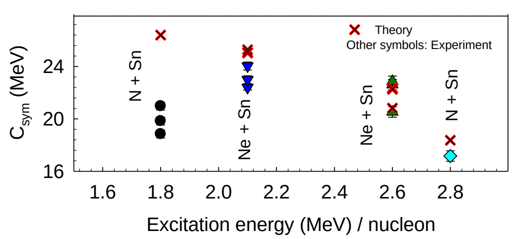

Fig. 3 C_{sym} of different systems at different excitation energy.

in Fig. 3. Experimentally obtained isoscaling, has been compared with the isospin dependent hybrid model of nuclear multifragmentation [3]. In this model, the initial stages of the reaction, when the projectile and target fuse together, is taken care of by BUU transport model. The fragmentation of the excited system is described by statistical model. The theoretical and experimental results for isoscaling are in good agreement with each other except the value at E^* =1.8 MeV/nucleon.

A decreasing trend of α, with E*/A (> 2) is consistent with the previous isoscaling studies and may be associated with the dependence of the symmetry energy coefficient on nuclear densities at different excitation energies [5]. It is observed that the temperature increases with excitation energy except at E^* = 1.8 MeV/nucleon. For E^* > 2 MeV/nucleon, C_{sym} has a decreasing trend. The values of C_{sym} at E*/A = 1.8 MeV is inconsistent with this trend. The temperature, α and C_{sym} are related through Eq. 2. The opposite trend of these parameters at E*/A = 1.8 MeV may be related to different reaction mechanism at below and above of E^* = 2 MeV/nucleon. This fact is further verified by the hybrid model of nuclear multifragmentation [3]. The model satisfactorily reproduces the experimental results at E^*/nucleon = 2.1, 2.6 and 2.8 MeV, but fails for 1.8 MeV. The theoretical calculations have been carried out considering the emission of primary fragments with 2 % pre-equilibrium emission. Thus the agreement between the theoretical and experimental results for E*/A = 2.1 -2.8 MeV, also rules out the contribution from secondary emissions, in isoscaling.

Conclusion

In conclusion, it is observed that IMFs (Z = 3 - 7) emitted from ^{20}Ne + ^{116,112},^{124}Sn, (E*/A ~ 2.1 and 2.6 MeV), ^{14}N + ^{116,112},^{124}Sn (E*/A = 1.8 MeV) and ^{14}N + ^{112,124}Sn (E*/A = 2.8 MeV) follow the isoscaling property. It is also observed that E* above 2 MeV/nucleon, C_{sym} has a decreasing trend. The value of C_{sym} at E^* = 1.8 MeV/nucleon is inconsistent with this trend which may be due to reduction or vanishing of multifragmentation below E^* = 2 MeV/nucleon.

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