Study of isoscaling properties in dissipative binary collisions

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Study of density dependence of symmetry energy in nuclear equation of state is one of the most interesting subjects in recent times. It has been shown experimentally that the ratio of the fragment yields, taken from two different reactions, follows an exponential dependence on the neutron number (N) and the proton number (Z) of the fragments - known as isoscaling behavior [1]. This isoscaling behavior observed in intermediate energy heavy ion reactions is apparently a general feature for any reaction involving thermal equilibration. Therefore, such isoscaling behavior is expected for low energy (E/A < 10 MeV) nuclear reactions. However, very few studies are available, where such isoscaling behavior has been seen [1]. Here, we have reported our recent experimental observations indicative of the isoscaling behavior in fragments emitted from the deep-inelastic collision.

The reactions studied in the present case, are ^{20}Ne (166.5 MeV and 147.5 MeV) + ^{56}Fe and ^{16}O (161.6 MeV and 143.8 MeV) + ^{58}Ni, populating the same nucleus with different N/Z ratio. The experimental details may be found in the reference [2]. The origin of the emitted fragments were studied and found to be emitted from a process faster than the compound nuclear type reaction known as highly damped deep inelastic reaction, the details of the fragment emission mechanism has been reported in the above reference [2]. Here, we have reported the isoscaling properties of the emitted fragments in these two reactions.

The ratio of the fragment yields, $R_{21}(N,Z)$, taken from two different reactions, 1 and 2, can be expressed by the relation [1]

$$R_{21}(N,Z) = \frac{Y_2(N,Z)}{Y_1(N,Z)} = Ce^{(N\alpha+Z\beta)} \quad .....(1)$$

here, $Y_1(N, Z)$, and $Y_2(N, Z)$ are the yields of the fragment in reaction 1 and 2, respectively. The numbers 1 and 2 refers to the composite formed in the reaction 1 (neutron-deficient) and reaction 2 (neutron-rich), respectively. 'C' is the normalization constant. α and β are the isoscaling parameters, which depend on the properties of the source of emitted particle. The parameter α depend on the symmetry energy of the system by the relation

$$\alpha = \frac{4C_{sym}}{T}\left(\frac{Z_1{}^2}{A_1{}^2} - \frac{Z_2{}^2}{A_2{}^2}\right) \quad ....(2)$$

where, C_{sym} and T are the symmetry energy and temperature of the composite system. (Z_1, A_1) and (Z_2, A_2) are the charge and mass number of the neutron-deficient and neutron-rich composites, respectively. The temperature, T, has been extracted using double isotope thermometer (DIT) [3] by taking the average of the values of temperature extracted from DIT using possible combinations of isotopes. Extracted temperatures of the both composites at E^*~124 MeV and ~110 MeV are 2.99(50) and 2.70(43) MeV, respectively.

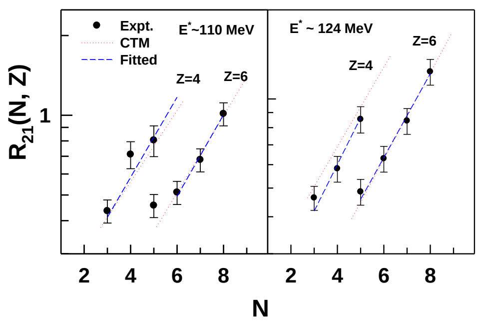

Fig. 1 Isotopic yield ratios, $R_{21}(N, Z)$, are plotted as a function of N for Z=4 and 6.

The ratios of experimentally measured isotopic yields, $R_{21}(N, Z)$, for the reactions, (1) $^{16}O + ^{58}Ni$ and (2) $^{20}Ne + ^{56}Fe$, have been extracted using Eq. (1) and plotted as a function of N in Figs 1 (for Z=4, 6) and 2 (for Z=3, 5) at two different excitation energies in left (E^*~110 MeV) and right (E^*~124 MeV). It is seen that the ratio for each element shows linear behavior in the semi logarithmic plot and aligns with the neighboring element quite well and the resulting slopes would then be α. The dashed lines are best fits to the data points with one value of α for all the elements. Theoretical simulations are performed in the framework of Canonical Thermodynamical Model (CTM) [4]. In CTM, the abundances of various fragments are determined by calculating their available phase space and found to be consistent within the experimental uncertainties. The red dotted lines shown in Figs. 1 and 2 are the prediction of CTM.

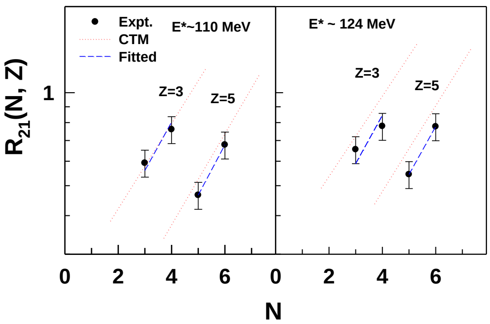

Fig. 2 same as Fig.1 for Z = 3 and 5

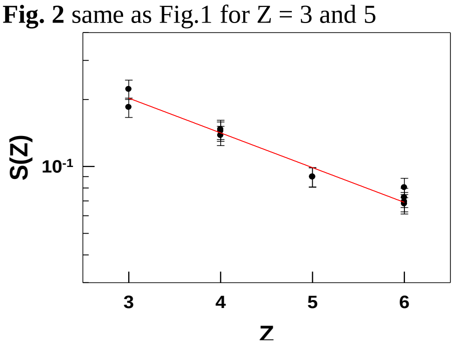

Fig. 3: S(Z) as a function of Z for E*~124 MeV.

Alternatively, the experimental data can be displayed compactly as a function of one variable, Z, by removing the dependence of the other variable using the scaled functions [1], defined by

$$S(Z) = R_{21}(N, Z)\, e^{-N\alpha} \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The S(Z) of different fragments lies on a single line on a semi logarithmic plot as a function of Z for the best fit value (shown in red solid lines) of α as shown in Figs. 3 (α =0.36 for E*~124 MeV) and 4 (α =0.39 for E*~110 MeV). The symmetry energies of the systems have been extracted and found to be 21.8± 1.8 MeV and 21.1± 1.7 MeV for excitation energies E^*~124 MeV and E^*~110 MeV, respectively.

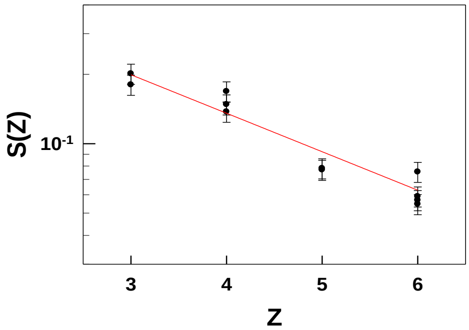

Fig. 4: S(Z) as a function of Z for E*~110 MeV

In summary, the ratio of isotopic yields of different fragments emitted from two reactions have been extracted and found to exhibit isoscaling behavior for both the excitation energies. These ratios have been compared with the CTM calculation and found to be consistent within the experimental uncertainty. The symmetry energies of the systems have been extracted and found to be consistent with the liquid drop model.

Acknowledgement: *one of the author V.S. like to thanks the UGC D S Kotharia for financial help for research No.F.4-2/2006(BSR)/PH/19-20/0072.*

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