Isoscaling in $^{13}C + {}^{12}C$ and $^{12}C + {}^{12}C$ reactions at ~6MeV/u

T. K. Rana[1*], C. Bhattacharya[1], S. Kundu[1], K. Banerjee[1], S. Bhattacharya[1], G. Mukherjee[1], T. K. Ghosh[1], J. K. Meena[1], P. Dhara[1], M. Biswas[1], H. Pai[1], K. Mahata[2], Suresh Kumar[2], K. Ramachandran[2], P. C. Rout[2], S. K. Pandit[2], V. Nanal[3] and R.G. Pillay[3]

[1]*Variable Energy Cyclotron Centre, 1/AF, Bidhan Nagar, Kolkata – 700 064, INDIA*
[2]*Nuclear Physics Division, Bhabha Atomic Research Centre, Trombay, Mumbai - 400085, INDIA,*
[3]*Deptartment of Nuclear and Atomic Physics,*
Tata Institute of Fundamental Research, Mumbai - 400085, INDIA
** email:tapan@veccal.ernet.in*

Introduction

Study of the density dependence of symmetry energy part of nuclear equation of state is one of the most interesting subject in recent years. Experimentally, the best possible means of studying the nuclear equation of state at subnormal nuclear density is through intermediate-energy heavy-ion reactions [1, 2]. In this kind of reaction, an excited nucleus (the composite of the projectile and the target nucleus) expands to a sub nuclear density and disintegrates into various light and heavy fragments in a process called multi fragmentation. By studying the isotopic yield distribution of these fragments one can extract important information about the symmetry energy and its density dependence.

It has been shown from experimental measurements that the ratio of the fragment yields, $R_{21}(N,Z)$, taken from two different reactions, 1 and 2, obeys an exponential dependence on the neutron number (N) and the proton number (Z) of the fragments - an observation termed as isoscaling [3-5]. The dependence is characterized by the relation

$$R_{21}(N,Z) = Y_2(N,Z)/Y_1(N,Z) = C.\exp(N\alpha + Z\beta) \quad (1)$$

where Y_2 and Y_1 are the fragment yields from the neutron-rich and the neutron-deficient systems, respectively. C is an overall normalization factor, and α and β are the parameters characterizing the isoscaling behavior. These isoscaling parameters α and β have been found to be sensitive to the density dependence of symmetry energy. These isoscaling behavior observed in intermediate energy heavy ion reactions is apparently a general feature for any reaction involving equilibration and thermalization. Therefore, such isoscaling behavior is also expected for low energy (E/A < 10 MeV) nuclear reactions. However, very few low energy reaction data are available where such isoscaling behavior has been seen [3]. Here we report our recent experimental observations indicative of the isoscaling behaviour in low energy nuclear reaction.

Experimental Details

The experiments have been performed at the BARC-TIFR 14UD Pelletron, Mumbai, using 77MeV ^{12}C, and, 75 MeV ^{13}C ion beams on a ^{12}C target (self supported, thickness ~ 90μg/cm^2). Different fragments have been detected using a 3-element telescope [6]. The telescope consisted of a 50 μm ΔE Single-sided Silicon Strip Detector (16 channels), 500 μm E/ΔE Double-sided Silicon Strip Detector (16 X 16 channels) and backed by four CsI(Tl) crystals (thickness ~ 6 cm). The detector telescope was placed at a distance 20 cm from the target. The angular range in the laboratory covered by the telescope was from 18^0 to 32^0. Typical angular resolution of each strip was $\pm 0.4^0$. All strips and the CsI(Tl) detectors were read out individually using standard readout electronics. A VME-based online data acquisition system developed at VECC [7], was used for the collection of data on an event-by-event basis. Typical two-dimensional spectrum obtained with two telescopes (50μm Δ E - 500 μm E and 500 μm ΔE - CsI(Tl)) are shown in Fig. 1 and Fig. 2 respectively. Separated bands corresponding to different isotopes for the fragments Li – C are clearly seen in Fig. 1., whereas the well separated bands for the isotopes of Z=1 are observed in Fig. 2.

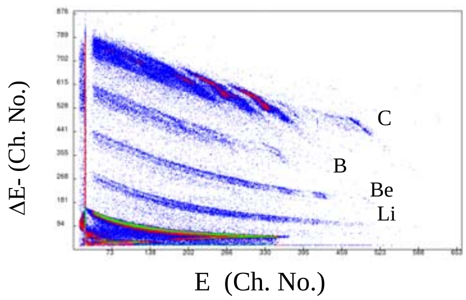

FIG. 1. Typical two-dimensional ΔE-E scatter plot between the 50 μm (*E*) and 500 μm(*E*) detectors

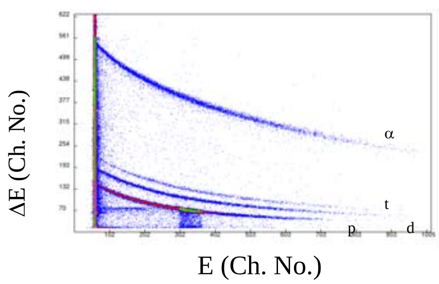

FIG. 2. Two-dimensional_E-E scatter plot between the 500μm (*E*) and 6 cm CsI(Tl)(*E*) detectors

Results and Discussions:

The ratio of isotope yields $R_{21}(N,Z)$, in two different systems, ^{13}C + ^{12}C and ^{12}C + ^{12}C, have been extracted using Eq. (1). Fig. 3 illustrates the isoscaling property observed with the fragments produced in the reactions ^{13}C + ^{12}C and ^{12}C + ^{12}C respectively. It is seen that the ratio for each element shows linear behavior in the logarithmic plot and aligns with the neighboring element quite well and the resulting slopes would then be α. Isotopes of the same elements are plotted with the same symbols. The solid lines are best fits to the data points with one common α value for all the elements. Alternatively, the data has been displayed in Fig. 4 compactly as a function of one variable, *Z*, by removing the dependence of the other variable using the scaled functions[3] , defined by

$$S(Z)= R_{21}(N,Z) \exp(-N\alpha) \quad (2)$$

The *S*(*Z*) of different fragments lies on a single line on a semilogarithmic plot as a function of *Z* for the best fit value of (α =0.453) as shown in Fig. 4. It is known that for the intermediate energy nuclear reactions that (1) the value of α depends upon the N/Z ratio of the system and (2) for any system, its value decreases as energy increases [4]. The preliminary analysis of the present data indicates signature of isoscaling in low energy nuclear reaction.

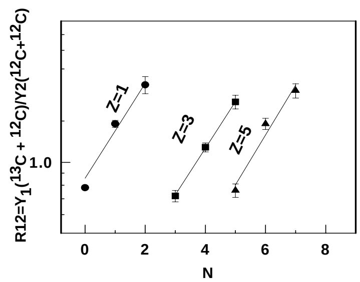

FIG. 3 Isotopic yield ratios are plotted as function of N for the reactions ^{13,12}C + ^{12}C

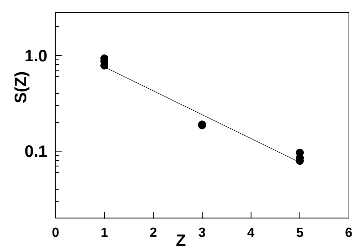

FIG. 4 S(Z) plotted as function of Z using α = 0.453

References

[1] B. A. Li *et al.*, , Int. J. Mod. Phys. E7,(1998)147.

[2] V. Baran *et al.*, Phys. Rep. **410**, (2005)335.

[3] M. B. Tsang *et.al*., Phys. Rev.**C 64** (2001) 041603 and references therein.

[4] D. V. Shetty *et. al*. , Phys. Rev C **76**, (2007) 024606. and references therein.

[5] G. Mukherjee et. al., Proc. IWM2007, Vol. **95**(2007)355**.**

[6] T. K. Rana *et. al.* Phys. Rev C **78**(2008) 027602

[7] P. Dhara *et. al. Proc:* DAE-BRNS.Symp. On Nucl. Phys. V**46B**(2003) 530.