Study of symmetry energy to temperature ratio in projectile fragmentation reaction

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Study of nuclear symmetry energy in intermediate energy heavy ion reactions is an important area of research for determining the nuclear equation of state. In this work, study of nuclear symmetry energy co-efficient to temperature ratio is done by using isoscaling source method, isoscaling fragment method, fluctuation method and isobaric yield ratio method in the framework of projectile fragmentation model [1] and compared with experimental data.

The model for projectile fragmentation reaction consists of three stages: (i) abrasion, (ii) multifragmentation (iii) evaporation. In heavy ion collision, if the beam energy is high enough then at a particular impact parameter three different regions are formed: (i) participant (ii) projectile like fragment or projectile spectator and (iii) target like fragment or target spectator. From the abrasion stage calculations the charge and mass of the PLF is obtained at different impact parameters. The multifragmentation stage calculation of each PLF created after abrasion at different impact parameters is done separately by the Canonical Thermodynamical Model (CTM) [2]. The canonical thermodynamical model assumes that due to density fluctuations each hot nuclear system (here projectile like fragments produced after abrasion stage) breaks up and reaches to an expanded freeze-out configuration at a particular temperature. The impact parameter dependence of freeze-out temperature is considered as $T(b) = 7.5 - 4.5(A_s(b)/A_0)$ where $A_s(b)$ is the mass of the projectile spectator created at an impact parameter b and A_0 is the mass number of original projectile. Finally, the decay of the excited fragments is calculated by the evaporation model [3] based on Weisskopf's formalism.

According to the isoscaling source method, for the fragmentation of two systems of charge Z_1, Z_2 and mass A_1, A_2 respectively at the same temperature T symmetry energy coefficient to temperature ratio is given by

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

where α is the isoscaling parameter which is related to the ratio of yields of fragments (N,Z) originating from two different systems by the equation

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

In the isoscaling fragment method, approximate grand canonical expression connecting C_{sym}/T with $Z/<A>$ of fragments by

$$\frac{C_{sym}}{T} = \frac{\alpha}{4\left[\left(\frac{Z}{<A_1>}\right)^2 - \left(\frac{Z}{<A_2>}\right)^2\right]}.$$

where, $\alpha(Z)$ is the isoscaling parameter of a fragment of charge Z and $< A_i >$ is the average mass number of a fragment of charge Z produced by source i(=1, 2).
In fluctuation method, by using Gaussian approximation of grandcanonical expression for clusters yield

$$\frac{C_{sym}(A)}{T} = \frac{A}{2\sigma_I^2(A)}.$$

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where $\sigma_I(A)$ indicates the width of the isotopic distribution of a cluster of size A, and $I = A - 2Z$. In deriving above expression, isospin dependence of the excitation energy and entropy associated to a given mass A are neglected.
According to the isobaric yield ratio method, obtained from grandcanonical expression for cluster yields, C_{sym}/T can be expressed as

$$\frac{C_{sym}(A)}{T} = -\frac{A}{8}[lnR(3,1,A) - lnR(1,-1,A)].$$

where, $R(I+2,I,A)$ is the yield ratio between two isobars differing by 2 units in isospin content as $R(I+2,I,A) = \frac{Y(I+2,A)}{Y(I,A)}$. Above equation assumes the Coulomb term in $lnR(3,1,A)$ and $lnR(1,-1,A)$ are same and in both ratios mixing entropy terms are neglected.

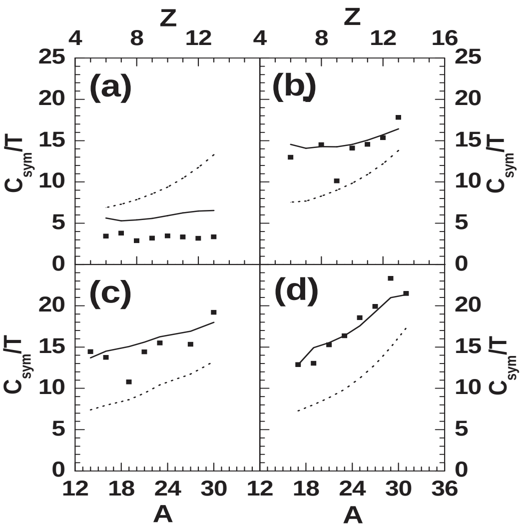

FIG. 1: Variation of C_{sym}/T with atomic number calculated by (a) isoscaling source method , (b) isoscaling fragment method. (c) and (d) represents the variation of C_{sym}/T with mass number calculated by fluctuation method and isobaric yield ratio method respectively. Experimental data (squires) compared with theoretical results: primary fragments (dotted line) and secondary fragments (solid line).

Since for calculating C_{sym}/T by isoscaling source method and fragment method, yields of two different reactions are required, therefore we theoretically study Ni^{58} on Be^9 and Ni^{64} on Be^9 by projectile fragmentation model and compared with experimental data at 140 Mev/nucleon energy. In fluctuation method and isobaric yield ratio method yields from a single reaction is required, hence only for Ni^{58} on Be^9 reaction the C_{sym}/T is calculated and compared with experimental data. In Fig.1 the results for theoretically calculated primary (after multifragmentation) and secondary (after evaporation) fragments and comparison with experimental data are shown.

From Fig. 1 we can conclude that, for hot fragments result from all four formulae are close to each other. Due to secondary decay the symmetry energy co-efficient to temperature ratio increases for isoscaling fragment method, fluctuation and isobaric yield ratio method but it decreases for isoscaling source method. After secondary decay, the result from isoscaling fragment method, fluctuation and isobaric yield ratio method are comparable and nice agreement between theoretical result and experimental data is observed for above mentioned methods. But for isoscaling source method the result is not comparable with other three method and the theoretical result and experimental data differ very much. For all the methods, in case of cold fragments deduced symmetry energy differ very much from input symmetry energy. Hence these methods are not good for extraction of symmetry energy from cold fragments.

References

[1] S. Mallik, G. Chaudhuri and S. Das Gupta, Phys. Rev. **C 84**, 054612 (2011).
[2] C. B. Das et al., Phys. Rep **406**, 1, (2005).
[3] G. Chaudhuri, S. Mallik, Nucl. Phys. **A 849**, 190 (2011).