Isospin physics from nuclear multifragmentation reactions around the VECC superconducting cyclotron energies

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The study of the nuclear equation of state is an important area of research in intermediate energy heavy ion reactions [1, 2]. Isoscaling [3–5] and isobaric yield ratio [4–6] are two well known methods which are used to study the nuclear equation of state and to extract symmetry energy coefficient at finite temperature from multifragmentation reactions. This paper focuses on theoretical study of isoscaling and isobaric yield ratio in nuclear multifragmentation reactions around the projectile beam energy available from VECC K=500 superconducting cyclotron.

The ratio of yields (R_{21}) from two nuclear reactions 1 and 2 having different isospin asymmetry (2 is more neutron rich than 1) exhibits an exponential relationship [3] as a function of neutron(N) and proton(Z) number i.e.

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

where α and β are isoscaling parameters and C is a normalization constant.The isobaric ratio of yields [6] of two different types of fragments having same mass number A but different isospin asymmetry $I = N - Z$ and $I^{'} = N^{'} - Z^{'}$ originating from a nuclear reaction is given by,

$$R[I^{'}, I, A] = \frac{Y(I,A)}{Y(I^{'},A)} \qquad (2)$$

The quantity $R[I^{'}, I, A]$ shows linear behavior with $A^{2/3}$ for I=1 and I'=-1 [5].

For studying isoscaling and isobaric yield ratio, ^{14}N+^{58}Ni and ^{14}N+^{64}Ni reactions at projectile beam energy 18 MeV/nucleon are simulated in the framework of isospin dependent hybrid model [7] of nuclear multifragmentation reactions. This model calculation consists of three different stages: (i) initial stage of the reaction is studied by Boltzmann-Uehling-Uhlenbeck equation based isospin dependent transport model (BUU@VECC-McGill) [8]. Excitation and isospin asymmetry of the compound nuclear system formed after the dynamical stage are determined by considering 90% of the total mass (remaining part is considered as pre-equilibrium emission). (ii) The Canonical Thermodynamical Model (CTM) [9] is used to study the fragmentation of the compound nuclear system corresponding to the excitation (E^*) and isospin asymmetry obtained at stage-i. (iii) Finally the secondary decay of excited fragments produced in stage-ii is studied by the evaporation model based on Weisskopf formalism [10].

Fig. 1 shows the isoscaling behavior obtained from the hybrid model calculation for ^{14}N+^{58}Ni and ^{14}N+^{64}Ni reactions at 18 MeV/nucleon. The left panel shows the ratios as function of neutron number N for fixed Z values, while the right panel displays the ratios as function of proton number Z for fixed neutron numbers (N). The dashed lines are drawn through the best fits of the calculated ratios. The lines in the plot approximately parallel to each other as it should be if the law of isoscaling described in Eq. 1 is obeyed. One vital assumption in Eq. 1 is that freeze-out temperature (T) of both the reactions are same. The concept of temperature

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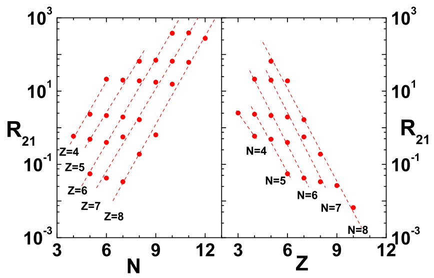

FIG. 1: Isotopic ratios(R_{21}) of multiplicities of fragments (N, Z) where reaction 1 and 2 are ^{14}N+^{58}Ni and ^{14}N+^{64}Ni respectively at 18 MeV/nucleon.

is quite familiar in heavy ion physics and it is usually calculated from double isotope ratio method or kinetic energy spectra of emitted particles [1]. But in both cases, sequential decay, Fermi motion, pre-equilibrium emission etc complicate the scenario of temperature measurement and the response of different thermometers is sometimes contradictory. The advantage of the present hybrid model calculation is that one can estimate the temperature of the intermediate energy heavy ion reactions directly from here which bypasses all such problems. It is directly obtained from this hybrid model calculation that, temperature for the ^{14}N+^{58}Ni reaction is 3.21 MeV while that for the ^{14}N+^{64}Ni reaction is 3.26

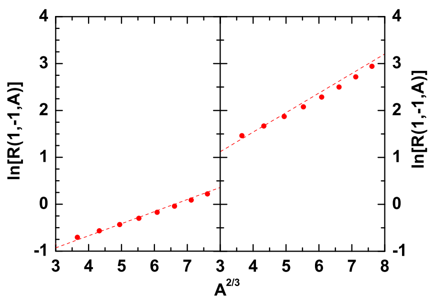

FIG. 2: Variation of isobaric yield ratio $lnR[1, -1, A]$ with $A^{2/3}$ for ^{14}N+^{58}Ni (left panel) and ^{14}N+^{64}Ni (right panel) reactions at 18 MeV/nucleon. Lines are drawn to guide the eyes.

MeV i.e. they are extremely close and this confirms strongly the assumption made for applying isoscaling equation.

Fig. 2 indicates the variation of isobaric yield ratio parameter $lnR[1, -1, A]$ with $A^{2/3}$ for ^{14}N+^{58}Ni (left panel) and ^{14}N+^{64}Ni (right panel) reactions at 18 MeV/nucleon. With the increase of isospin asymmetry, the effect of particle fluctuation as well as secondary decay is more, hence slight deviation of the calculated ratios from linear behavior is visible for ^{14}N+^{64}Ni reaction compared to that of ^{14}N+^{58}Ni reaction.

Hence, from this isospin dependent hybrid model calculation it can be concluded that light fragments originated from nuclear multifragmentation experiments around the projectile beam energy available from VECC K=500 cyclotron will also show linear behavior for determining isoscaling and isobaric yield ratio parameters. Most important significance of using this newly developed hybrid model is direct estimation of temperature of the reactions which confirms the important assumption of isoscaling equation, that is, temperature of both the reactions are very close.

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