Effect of secondary decay on isoscaling from the canonical thermodynamical model

Gargi Chaudhuri* and Swagata Mallik
Physics Group, Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata 700 064, INDIA

The canonical thermodynamical model has been used earlier to explain the isoscaling property of primary fragments in projectile fragmentation (CTM) [1, 2]. In experiments however, most fragments decay to their stable ground states before reaching the detectors. We investigate here the effect of evaporation from primary fragments on isoscaling. To this end, we develop an evaporation code and couple it with the CTM. We study projectile fragmentation reactions before and after evaporation using ^{58}Ni and ^{64}Ni projectiles on ^{9}Be and ^{181}Ta targets and compare our results with the experimental data.

The main assumption of CTM is that the compound nuclear system formed in a collision between the projectile and the target nuclei remains in a thermodynamic equilibrium at a temperature T in a freeze-out volume (greater than the normal nuclear volume) and then it partitions into different fragments. The detailed description of this model can be found in Ref. [1].

In the present calculation, the excited primary fragments produced by CTM are used as input to the evaporation code. The excited primary fragments can decay by emitting n, p, d, t, He^3, α, and γ. The particle decay widths are obtained using the Weisskopf's evaporation theory. Giant dipole gamma quanta emission width is calculated by the formula given by Lynn. Fission is also included as a de-excitation channel though for nuclei of mass < 100 its role is quite insignificant. Fission width is calculated using simplified Bohr-Wheeler formula. After calculating the widths of the above mentioned eight decay channels, whether an emission has occurred or not is decided by a Monte-Carlo simulation. If the emission has taken place, then the type of the emission is obtained by another Monte-Carlo simulation using partial widths of the decay channels. The kinetic energy of the emitted particle is subsequently determined by a third Monte-Carlo sampling of its energy spectrum. The energy, mass and charge of the nucleus is adjusted after each emission. This procedure is followed for each of the primary fragments produced at a fixed temperature and then repeated over a large ensemble of the compound system. The value of the observables are calculated as the ensemble averages. The number and type of particles emitted and the final decay product in each event is registered. The evaporation residues (or fission fragments) are suitably accommodated into the fragment distribution.

It is observed from the experimental data[3] that the light fragments emitted from the ^{58}Ni and ^{64}Ni systems exhibit the linear isoscaling behaviour represented by the equation

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

where the isoscaling ratio $R_{21}(N,Z)$ is factored into two fugacity terms α and β, which contain the differences of the chemical potentials for neutrons and protons of the two reaction systems. $Y_2(N,Z)$ refers to the yield of fragment(N,Z) from system 2 which is usually taken to be the neutron-rich one and $Y_1(N,Z)$ refers to the same from system 1. C is a normalization factor of the isoscaling ratio.

In our calculation, we take the dissociating system as $^{58}Ni +^{9} Be(N_0 = 35, Z_0 = 32)$ and $^{64}Ni +^{9} Be(N_0 = 41, Z_0 = 32)$ at a temperature of 5.8 MeV. Fig.1 shows the isoscaling results for Ni on Be system for the primary

*Electronic address: gargi@veccal.ernet.in

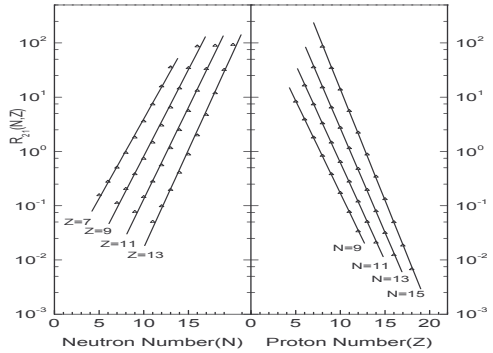

FIG. 1: Ratios(R_{21}) of multiplicities of primary fragments of producing the nucleus (N, Z) where reaction 1 is ^{58}Ni on ^{9}Be and reaction 2 is ^{64}Ni on ^{9}Be.

fragments. The ratio R_{21} is plotted as function of the neutron number (left panel) for fixed Z =7,9,11,13 and as a function of proton number (right panel) for fixed N=9,11,13,15. The solid lines in the above figure are best linear fits to the calculated R_{21} ratios.

Fig.2 displays the isoscaling results after evaporation. The ratio R_{21} is plotted as function of the neutron number (left panel) for fixed Z =7,9,11,13 and as a function of proton number (right panel) for fixed N=9,11,13,15. The lines in this figure are also best linear fits

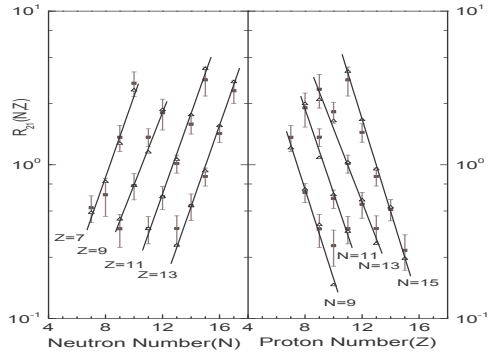

FIG. 2: Ratios(R_{21}) of multiplicities of secondary fragments of producing the nucleus (N, Z) where reaction 1 is ^{58}Ni on ^{9}Be and reaction 2 is ^{64}Ni on ^{9}Be.

to the calculated R_{21} ratios (triangles) while the experimental ratios [3] are shown as solid squares with error bars.

While comparing the isoscaling results before and after evaporation, it is evident that the isoscaling is valid for a limited range of isotopes for the secondary fragments as compared to the primary ones. One can conclude from this that isoscaling is approximately valid in the case of the secondary fragments. Also due to the effect of secondary decay the magnitude of isoscaling parameters decreases and matches well with the experimental values. The temperature required to reproduce isoscaling data with the primary fragments is about 8 MeV[2]. We also perform calculations for the $^{58}Ni+^{181}Ta$ and $^{64}Ni+^{181}Ta$ reactions and obtain the isoscaling parameters at a temperature of 6.2 MeV. We also get similar effect of decreasing the magnitude of α and β with secondary decay. The calculated isoscaling parameters of primary and secondary fragments as well as experimental data are shown in Table-I.

Target material	Isoscaling parameters	primary	secondary	experimental
^{9}Be	α	0.713	0.580	0.566
	β	-0.849	-0.634	-0.621
^{181}Ta	α	0.619	0.459	0.432
	β	-0.682	-0.489	-0.487

TABLE I: Best fit and experimental values of the isoscaling parametrs α and β for the two targets ^{9}Be and ^{181}Ta.

We therefore conclude that the effect of secondary decay results in a closer agreement with experimental isoscaling parameters.

The authors gratefully acknowledge valuable discussions with Prof. Subal Dasgupta.

References

[1] C. B. Das et al., Phys. Rep **406**, 1, (2005).
[2] G. Chaudhuri et al., Nucl. Phys. A**813**, 293-313 (2008).
[3] M. Mocko, PhD thesis, Michigan State University 2006.