Entropy production and its dependance on the asymmetry of a reaction

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Introduction

The characteristic of preserving the traces of hot and dense state of nuclear matter makes entropy as a crucial parameter to probe the physics behind nuclear reactions. Siemen and Kapusta were amongst the first to device the formulation for entropy [1]. They calculated the entropy using deuteron to proton ratio [1]. Further, Bertch and Cugnon also took light clusters like t, ^{3}He, ^{4}He into account [2], and defined the entropy as;

$$S_N = 3.945 - ln\tilde{R}_{dp}, \tag{1}$$

where

$$\tilde{R}_{dp} = \frac{d_{like}}{p_{like}} = \frac{d + \frac{3}{2}(t + {}^3He) + 3\ {}^4He}{p + d + t + 2\ {}^3He + 2\ {}^4He}. \tag{2}$$

Later on, to calculate the entropy in model calculations, Doss *et al* [3] parameterized it as:

$$\tilde{R}_{dp} = \frac{d_{like}}{p_{like}} = \frac{Y_2 + \frac{3}{2}Y_3 + 3Y_4}{N_p}, \tag{3}$$

where Y_n stands for the number of fragments with mass 'n' in one event. Here, the participant proton multiplicity (N_p) is calculated as:

$$N_p = \Big[\frac{Z_p + Z_T}{A_P + A_T}\Big][Y_1 + 2Y_2 + 3Y_3 + 4Y_4]. \tag{4}$$

During the last few years, Puri and collaborators have performed extensive studies of entropy production using n-body dynamical models [4, 5]. They have examined the role of various entrance channel parameters and found results consistent with the experimental data. Their study also showed the role of isospin asymmetry on the production of entropy. But till now, all the studies were limited to symmetric reactions only [1–6] and no efforts were reported that explore the behavior of entropy production for different mass regions and different mass asymmetries. Our studies will be in this direction. The interest in the present study is to see the behavior of entropy production for different mass regions and for different target/projectile mass asymmetries. We will also see how the entropy production can be correlated to fragment production.

Results and discussions

We simulated the reactions of ^{18}F+^{22}Ne, ^{36}Ar+^{44}Ca, ^{70}Ge+^{90}Zr, ^{108}Cd+^{132}Ba and ^{10}B+^{30}Si, ^{20}Ne+^{60}Ni, ^{40}Ca+^{120}Te, ^{60}Ni+^{180}W. The first set of reactions have the mass asymmetry parameter η=0.1 and the later set have η=0.5. The reactions are studied for the central geometries and in the framework of Quantum Molecular Dynamics (QMD) model [7]. The incident energy for each system is fixed corresponding to the lab energy of 400 MeV/nucleon for ^{197}Au+^{197}Au reaction. In Fig. 1, we display the entropy per nucleon as a function of total system mass (A_{Total}) for two fixed mass asymmetries of η=0.1 (triangles) and η=0.5 (inverted triangles). From the figure, it is clear that the entropy is independent of the total system mass. We also note that the value of entropy changes roughly by maximum of 5% for different mass asymmetries. This behavior is connected to the invariance of the breakup temperature (fragment production) of the system i.e., T$\simeq$ 5 MeV. To explore this, we

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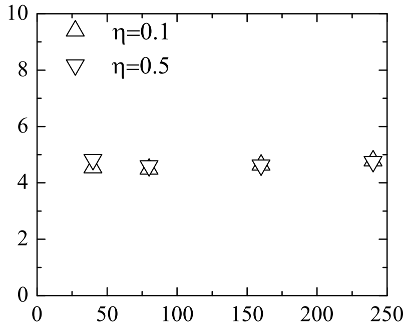

FIG. 1: The entropy per nucleon as a function of total system mass (A_{Total}) for two mass asymmetry of the reaction. The symbols are explained in the text.

study the fragment multiplicity behavior for the same reactions. The results are displayed in Fig. 2.

From the figure, we note that with increase in system mass, the value of mean size of largest fragment($< A_{max} >$), multiplicity of free nucleons ($< N_{FNs} >$) [$1 \leq A_f \leq 1$], light charged particles ($< N_{LCPs} >$) [$2 \leq A_f \leq 4$] and the intermediate mass fragments ($< N_{IMFs} >$) [$5 \leq A_f \leq A_{Total}/3$] increases linearly. The slopes obtained for the linear fit at fix η are shown in respective panels. The behavior of fragment number with increase in total system mass reflects its dependance on the available total energy and number of nucleons involved for a reaction. As the total energy increases for larger system masses, therefore, total number of fragments also increases due to the reason that production occurs at same temperature. More interesting results are observed, if we compare the results for two mass asymmetries in the light of invariance of entropy (shown in Fig.1). We see that although the entropy production is almost invariant, the fragment multiplicities depend on the mass asymmetry of the reaction. Thus even if the system expands isotropically during the initial stages of the reaction, the production of fragments (that is set up at much later time of the reaction) is solely not dependent on the entropy and the mass asymmetry also plays crucial role for fragment production. Our analysis is consistent with the results reported in Refs.[8].

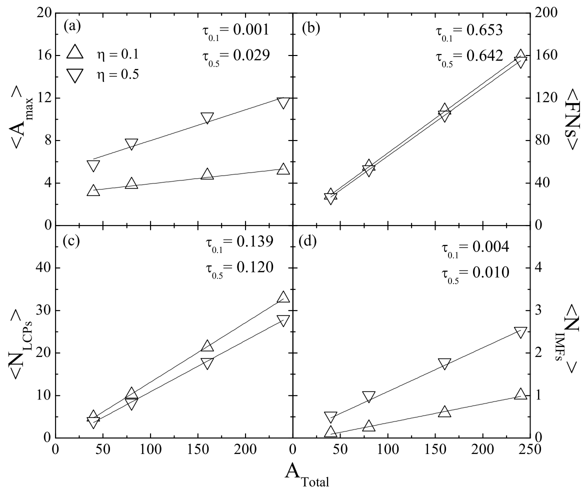

FIG. 2: The mean size of largest fragment ($< A_{max} >$), and multiplicity of free nucleons $< N_{FNs} >$, light charged particles ($< N_{LCPs} >$) and intermediate mass fragments ($< N_{IMFs} >$) as a function of total system mass (A_{Total}) for two mass asymmetry values.

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