The production of entropy in central Ca+Ca and Nb+Nb collisions

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Introduction

One of the motivation to study the heavy-ion reactions at relativistic energies is to produce and infer the properties of hot and compressed baryonic matter. Recent studies have indicated clear demarkation of the hot participant matter and relatively cold spectator regimes in heavy-ion reactions [1]. The baryonic entropy S_N is one of the important thermodynamical variables that preserves the signature of early violent stage of the reaction. The entropy produced in a heavy-ion reactions can be studied via yields of deuteronlike (d_{like}) and protonlike (p_{like}) clusters [2, 3]. However, the measurement of entropy is valid during the fireball formation which takes place for ephemeral times. Further, the fireball formation is also affected by other factors like the overlapping volume, beam energy, and density reached in a reaction. In the present paper, we try to estimate the baryonic entropy S_N from the yield ratio of deuteronlike to protonlike clusters in central collisions of $^{40}Ca +^{40} Ca$ and $^{93}Nb +^{93} Nb$. Our calculations are performed within the framework of *quantum molecular dynamics* (QMD) model [4] at the times when *n-n* collisions cease almost and average nucleon density ϱ also saturates.

The Model

In the quantum molecular dynamics (QMD) model, each nucleon is represented by the Gaussian wave function in phase space:

$$\psi_i(\mathbf{r}, \mathbf{p}_i, \mathbf{r}_i) = \frac{1}{(2\pi L)^{3/4}} e^{[\frac{i}{\hbar}\mathbf{p}_i(t)\cdot\mathbf{r} - \frac{(\mathbf{r}-\mathbf{r}_i(t))^2}{4L}]}. \quad (1)$$

The Gaussian wave packet has fixed width $\sqrt{L}$ which equals 1.08 fm. The centroid of these Gaussians wave packets move in phase space according to classical equations of motion [4]:

$$\dot{\mathbf{r}}_i = \nabla_{\mathbf{p}_i}\langle\mathcal{H}\rangle, \dot{\mathbf{p}}_i = -\nabla_{\mathbf{r}_i}\langle\mathcal{H}\rangle, i = 1, ..., N. \quad (2)$$

Here $\mathcal{H}$ is the total Hamiltonian of the system of N-nucleons. To estimate the entropy, we use the generalized formula [3]:

$$S_N = 3.945 - \ell n(d_{like}/p_{like}). \quad (3)$$

Following Ref. [5], we define the yield ratio d_{like}/p_{like} in the following way:

$$\frac{d_{like}}{p_{like}} = \frac{Y(A=2) + \frac{3}{2}Y(A=3) + 3Y(A=4)}{N_p}, \quad (4)$$

where Y(A=n) stands for the yield of fragments with mass 'n' in one event. Analogous to experimental results, we calculate the total participant proton multiplicity N_p as:

$$N_p = \frac{Z_P+Z_T}{A_P+A_T}[Y(A=1) + 2Y(A=2) + 3Y(A=3) + 4Y(A=4)], \quad (5)$$

where $Z_P + Z_T$ and $A_P + A_T$ define the total charge and mass of the colliding system.

Results and Discussion

Turning to model calculations, we simulated the central collisions of $^{40}Ca +^{40} Ca$ (at 400 and 1050 AMeV) and $^{93}Nb +^{93} Nb$ (at 400 and 650 AMeV). The entropy is then estimated via Eq.(3), for unfiltered events. Figure 1 shows the model calculations for entropy S_N along with experimental data taken with Plastic Ball/Wall detector [6]. Clearly, one sees that calculated entropies are in nice agreement with experimental data at all incident energies. Further, the magnitude

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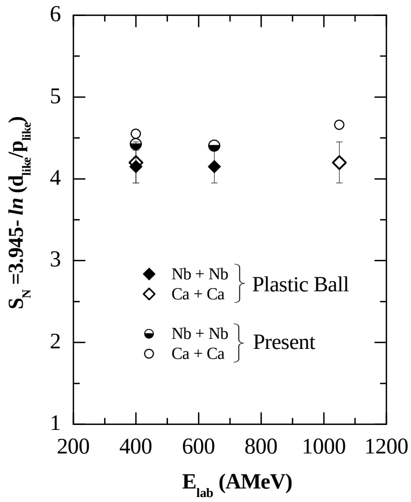

FIG. 1: The baryonic entropy S_N vs beam energy E_{lab} for the central collisions of $^{40}Ca +^{40} Ca$ and $^{93}Nb +^{93} Nb$. Also shown are entropy values extracted by the Plastic Ball group [6] at maximum baryon charge number $(d_{like}/p_{like})_{max}$ (Preliminary results).

of entropy produced is almost independent of beam energy as well as system size. These preliminary results suggest that QMD model contains necessary ingredients to describe the physics of fireball formation and dynamical emission of light clusters [7].

Acknowledgments

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