Correlation between temperature, density and nuclear stopping in heavy ion collisions

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Introduction

It is well known that, nuclear stopping governs most of the dissipated energy in central heavy ion collisions and constrains the different reaction mechanisms over large domain of incident energies. It also provides information about the nuclear equation of state, nucleon-nucleon cross section, as well as degree of equilibrium reached in a heavy-ion collisions [1]. The optimal condition for the nuclear matter, compressed to form a dense medium is that, the two colliding nuclei get fully stopped during the explosion of the reaction [2]. The information about the nuclear stopping can be obtained by studying the rapidity distributions of the fragments or free nucleons in the transverse and longitudinal directions. It is represented by the observable known as varxz [3]:

$$varxz = \frac{varx}{varz} = \frac{\sigma^2(x)}{\sigma^2(z)} \quad (1)$$

Clearly, for the fully equilibrated system *varxz* should be close to unity. The *varience* is calculated using the relation $fwhm = 2.36 * \sqrt{variance}$ [3, 4]. Where the *variance* is *varx* (variance of transverse rapidity distribution) or *varz* (variance of longitudinal rapidity distribution). The rapidity distribution is defined in Ref. [5]. The other quantities linked with the dense matter are the nuclear matter density and temperature. In our approach, nuclear matter density is calculated as defined in Ref. [6]. In the present work, extraction of the temperature is based on the local density approximation, i.e. one deduces the temperature in a volume element surrounding the position of each particle at a given time step [6]. Recent study on the density and temperature reached in a heavy ion reaction showed a significant mass dependence for the temperature of the neutron rich system [7]. Tremendous work has been done to study the correlation between the degree of nuclear stopping and the observable originating from the early stage in a non-central collision like the sideward flow [3]. However, little efforts have been made to study the correlation between the degree of nuclear stopping with maximal value of the temperature and density reached in heavy ion collisions. In the present paper, our aim is to study the complete systematics of global stopping and its correlation with maximal value of the temperature and density reached in a heavy ion collisions. The present study is performed within the framework of isospin-dependent quantum molecular dynamics (IQMD) model [8].

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Results and discussion

For the present study, we simulate the reactions of Ca + Ca, Ni + Ni, Ru + Ru, Xe + Xe and Au + Au using the soft equation of state in the energy range between 90 MeV/nucleon and 2000 MeV/nucleon.

Fig.1 display the system charge dependence of maximum temperature ($< T >_{max}$) [panel (a)], maximum density ($< \rho >_{max}$) [panel (b)] and *varxz* [panel (c)], respectively. It has been observed that, density as well as temperature reached in light nuclei is much less compared to heavier nuclei. This is not unexpected since the degree of stopping is much less in the reaction particular for lighter nuclei. Moreover, [panel (c)] represents the system charge dependence of *varxz* at an incident energy of 400 MeV/nucleon. Scaled by 1.38, the theoretically observed *varxz* is compared

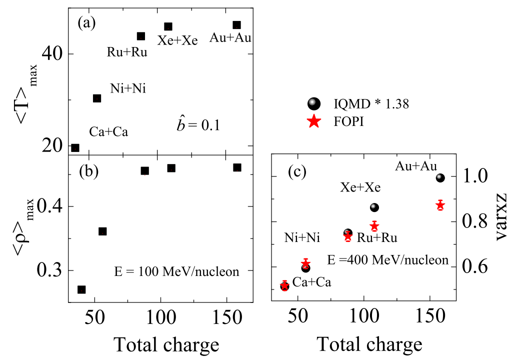

FIG. 1: System charge dependence of maximum temperature ($< T >_{max}$) [panel (a)], maximum density ($< \rho >_{max}$) [panel (b)] and varxz [panel (c)] respectively.

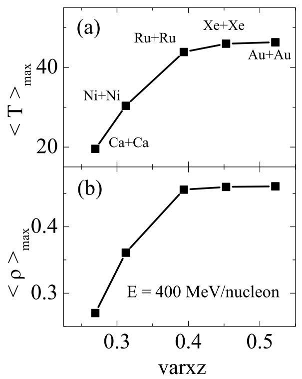

FIG. 2: Correlation between maximum temperature ($< T >_{max}$), maximum density ($< \rho >_{max}$) and varxz [panel (a)] and [panel (b)] respectively.

with experimental results of FOPI collaboration [3]. It is clear from the figure that as we go from lighter to heavier system, the thermalization increases. Thus heavier systems are better thermalize as compared to lighter systems. Moreover, even for the heavier systems the *varxz* short of unity, meaning that nuclear collisions are not fully stopped even for the heavier system in central collisions. These findings are also in agreement with Ref.[3].

From the above discussion, it is clear that maximum temperature, density and *varxz* show similar behavior. In order to study the direct correlation between these observable, we display in Fig.2, the maximum temperature ($< T >_{max}$), maximum density ($< \rho >_{max}$) as a function of *varxz* [panel (a)] and [panel (b)], respectively. One finds that, these variables are closely correlated with each other. The degree of nuclear stopping (*varxz*) in correlation to ($< T >_{max}$) and ($< \rho >_{max}$) shows similar behavior. The curves show first an increase and then saturation effect. This happens because, the nuclear stopping decreases with increase in incident energy. With this increasing transparency, the compression of the fireball becomes less and accordingly the system does not experience an increasingly high density and temperature. Thus, we can say that, the effective density and temperature reached in the early phase of a reaction are strongly correlated with the degree of stopping and nuclear stopping is determinant to produce highly compressed nuclear matter.

Acknowledgments

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