Probing density and temperature in heavy-ion collisions

Rajiv Chugh and Rajeev K. Puri*
Physics Department, Panjab University, Chandigarh - 160014, INDIA

Introduction

Heavy-ion collisions are the only generator of hot and dense nuclear matter in laboratory frame. The analysis of temperature and density of nuclear matter leads to formulate equation of state (EOS) of nuclear matter. This helps to understand the situation at the time of some celestial phenomenon or even the big bang. On the same lines, as a part of this analysis, we are interested in the basic, time evolution of temperature and density. Microscopic study is expected to give some naive facts.This may involve the occurance of maximum temperature and density during heavy-ion collision reaction or even the link between maximum and average values for the sake of homogeneity in the matter. The study would also involve the system size also. Under certain assumptions theoretical models have been generated to simulate the heavy ion collision reactions. One such transport model to see time evolution of such an event is quantum molecular dynamics (QMD) model[1].

Using the model we try to achieve density profile and temperature profile of state at reaction time. This would help us to mark the region or epicenter in coordinate frame. The position or/and momentum during reaction time can only be speculated using theoretical transport models, in which realtime experiments are lacking.

The Model

In QMD, nucleons are treated as gaussian wave packets instead of point particles,

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

where p_i and r_i are the position and momentum of i^{th} particle. The width of gaussian wave packet is taken corresponding to size of nucleon. The particles are made to propagate using classical equations of motion,

$$\frac{d\mathbf{r}_i}{dt} = \frac{dH}{d\mathbf{p}_i}, \quad (2)$$

$$\frac{d\mathbf{p}_i}{dt} = -\frac{dH}{d\mathbf{r}_i}, \quad (3)$$

where Hamiltonian H is given by:

$$H = \sum_i \frac{\mathbf{p}_i^2}{2m_i} + V^{tot}, \quad (4)$$

with

$$V^{tot} = V^{loc} + V^{Yuk} + V^{Coul}. \quad (5)$$

Each nucleon is in the mean field involving Skyrme potential (V^{loc}), Yukawa (V^{Yuk}) and Coulomb potential (V^{Coul}). There is option to generate equation of state with compressibility(K) $>$ 290 MeV or $<$ 290 MeV, but here we consider K = 380 MeV i.e. hard EOS. The collisions among the particles are controlled through constant isotropic cross section of 55 mb.

Results and Discussion

Here we discuss time evolution of density and temperature simultaneously by simulating the collision action between symmetric nuclei pairs of $Ne^{20} + Ne^{20}$, $Ca^{40} + Ca^{40}$, $Nb^{93} + Nb^{93}$ and $Er^{168} + Er^{168}$ at energy of 200 MeV per nucleon. All reactions are at the reduced impact parameter (b/b_{max}) 0.25.

In Fig. 1, maximum density (1(a)) and maximum temperature (1(b)) are taken against the time (fm/c) for the considered systems. We observe, that it is not only the energy which decides the interaction time, but

*Electronic address: rkpuri@puchd.in

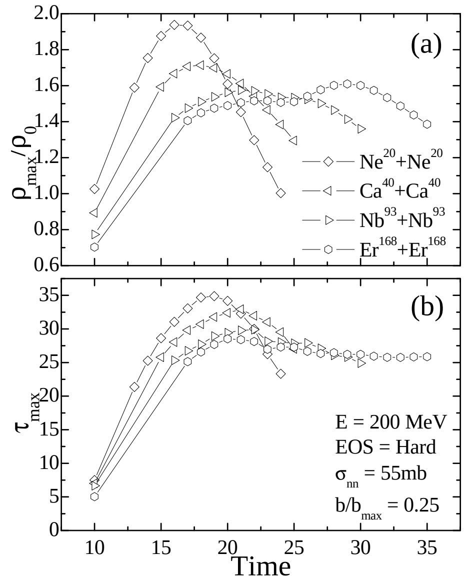

FIG. 1: Time evolution of maximum density (a) and maximum temperature (b) is plotted for systems of different mass. The collisions are with same center of mass energy of 200 MeV/nucleon and at same geometry with reduced impact parameter of 0.25

also the size of the participating nuclei, in agreement with Ref. [2]. The compression stage sustains there for longer time for the heavier systems.

This is also worth observing that the compression immediately does not cause the rise in temperature especially in lighter systems, there exists a time lapse [3]. This also provokes the question that the regions may also be different for the occurance of maximum density and temperature. This time gap is hardly observed in case of average values of density and temperature , shown in fig. 2.

Moreover it is also observed that the in heavier systems maximum density and average density are not differing much, suggesting the uniform distribution in system. In other words the state of homogeneity is obtained, where the equilibrium can not be achieved This requires a critical and careful analysis

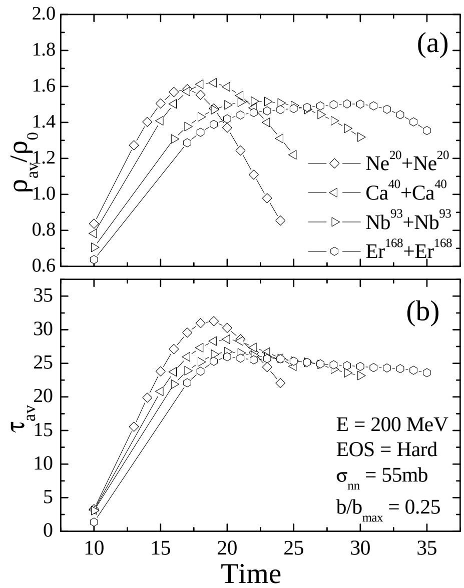

FIG. 2: Time evolution of average density (a) and temperature (b) in same reactions mentioned in fig.1.

and interesting results are expected.

Acknowledgement

We are thankful to Dr. Aman D. Sood for his valuable contribution.

References

[1] J. Aichelin, Phys. Rep. **202**, 233 (1991).
[2] A. D. Sood and R. K. Puri, Phys. Rev. C **69,** 054612 (2004) and references therein.
[3] R. Chugh and R. K. Puri to be submitted in Phys. Rev. C.