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Role of Isospin Momentum Dependent Interactions in Extreme Conditions

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In the present study, the role of isospin in the momentum dependent interactions has been studied through the stopping observables. For this, the simulations have been carried out within the framework of IQMD and IQMD(Th01) model at the central collisions for various systems at an incident energy of 100 MeV/nucleon. The nucleonic interactions (momentum dependent) as a function of isospin marginally affect the density and temperature. This motivation will help to further investigate the role of iso-MDI on the other observables for the nuclear matter under extreme conditions.

Key Words : Heavy Ions; Interactions; Phase Space; Temperature; Nuclear Stopping; Equilibrium; Reduced Rapidity

Introduction

Since the very early days of heavy-ion experiments, it has been understood that collisions of two heavy ions could create the nuclear matter with density and excitation energy severely different from that of the ordinary matter surrounding us and how this ordinary matter behaves, when subjected to different conditions is described by the equation of state (EOS). The EOS depends on the interactions and properties of the particles in the matter. So, the understanding of nucleon-nucleon (N-N) interaction is most important problem in nuclear physics. The understanding of N-N interaction gives the insight into many nuclear properties and nuclear reactions mechanism, for instance, the binding energies, incompressibility factor, nuclear structure, fusion-fission reactions and so on. Therefore, knowledge of the form of N-N interaction potential is of great significance for us to explain the nature of the nucleus and to study the nuclear reaction mechanism. In IQMD model, by combining the known Skyrme forces with the momentum dependent interaction (MDI), two different parameter sets namely soft momentum dependent (SMD) and hard momentum dependent

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(HMD) were proposed (Aichelin, 1991). The MDIs lead to additional repulsion between the nucleons when boosted in heavy-ion collisions (HICs) (Cooper *et al*., 1987). But these MDIs were not isospin dependent. The MDIs have a significant influence on the reaction outcome. The EOS with momentum dependence is found to give a more realistic view of the HICs, as compared to the static one, especially in the peripheral collisions, when the nuclear matter is mildly excited (Kumar *et al*., 2008). Study of single cold nucleus initialized with soft and SMD EOS, justifies the role of MDI as a destabilizing factor, which results in an enhanced emission of free nucleons (Vermani *et al*., 2009). Motivated by these interesting aspects, we here study the impact of MDI and its isospin dependence i.e. iso-MDI on the nuclear stopping which is one of the essential observables that are necessary to understand the basic reaction dynamics. To explore the elegant role of isospin in heavy-ion reactions, we perform an investigation by perceiving the MDI to be isospin dependent. For the present analysis, the methodology employed for the isospin MDI has been taken from (Liu *et al*., 2005). The present study is carried out within the framework of isospin dependent quantum molecular dynamics (IQMD) model (Hartnack *et al*., 1998) and its iso-MDI version namely IQMD(Th01) (Vinayak *et al*., 2013).

Results and Discussion

For the present analysis, simulations have been carried out for the central collisions of the systems $^{40}_{20}Ca+^{40}_{20}Ca$, $^{44}_{20}Ca+^{44}_{20}Ca$, $^{48}_{20}Ca+^{48}_{20}Ca$, $^{52}_{20}Ca+^{52}_{20}Ca$, $^{56}_{20}Ca+^{56}_{20}Ca$, $^{60}_{20}Ca+^{60}_{20}Ca$, $^{84}_{28}Ni+^{84}_{28}Ni$, $^{120}_{40}Zr+^{120}_{40}Zr$, and $^{162}_{54}Xe+^{162}_{54}Xe$ at an incident energy of 100 MeV/nucleon within the framework of IQMD and IQMD(Th01) model. A soft EOS with MDI and iso-MDI has been employed along with the reduced isospin-dependent cross-section (0.9 of σ_{NN}^{free}).

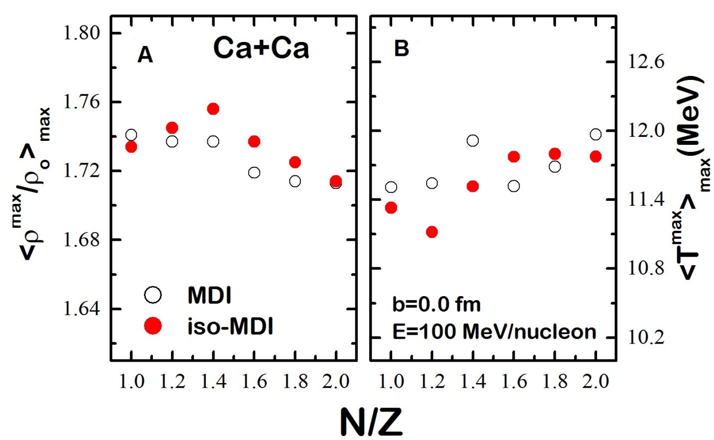

Fig. 1: The N/Z dependence of the $<\frac{\rho^{max}}{\rho_0}>_{max}$ (A) and $<T^{max}>_{max}$ (B) for the colliding system Ca+Ca with MDI and iso-MDI

The maximum density reached during the collision of two heavy ions is affected by the N-N interactions. To understand the role of isospin in MDI, the N/Z dependence of the maximum value of the maximum density ($< \frac{\rho^{max}}{\rho_0} >_{max}$) and the maximum value of the maximum temperature ($< T^{max} >_{max}$) has been analyzed in Fig. 1 for MDI and iso-MDI. The maximum of the density and temperature corresponds to their maximum value reached during the whole time span of the reaction. The $< \frac{\rho^{max}}{\rho_0} >_{max}$ with MDI and iso-MDI is 1.73 and 1.75 respectively. The $< \frac{\rho^{max}}{\rho_0} >_{max}$ achieved during the collision is more for the iso-MDI. However, this difference is marginal because in central collisions, the N-N collisions are more frequent which results in complete destruction of the initial correlations. In iso-MDI, the neutron-proton correlations are stronger than the neutron-neutron and proton-proton correlations. Therefore, an additional repulsion due to MDI and reduction of this additional repulsion due to iso-MDI does not mark any significant variation. The another quantity linked with the compressed nuclear matter is temperature. The $< T^{max} >_{max}$ with MDI and iso-MDI is 11.77 MeV and 11.96 MeV respectively. The temperature is found to give the similar behaviour as that of density. The slight variation in temperature due to iso-MDI is due to the variation in the density. These two quantities have also been investigated many times in the literature (Vinayak and Kumar, 2012; Khoa *et al*., 1992) but no such investigation has been made with iso-MDI. Also, $< \frac{\rho^{max}}{\rho_0} >_{max}$ and the $< T^{max} >_{max}$ reached with MDI and iso-MDI are comparable for the various isotopic systems of Ca.

There are several different ways to define the degree of equilibrium. In many cases, nuclear stopping has been studied by baryon rapidity distributions (dN/dY) at various beam energy ranges (Hong *et al*., 1998). In this work also, the question of equilibrium has been addressed with the help of rapidity distribution. The rapidity distribution of the *i*-th particle is defined as (Dhawan *et al*., 2006)

$$Y(i) = \frac{1}{2} ln \frac{E(i) + p_z(i).c}{E(i) - p_z(i).c} \tag{1}$$

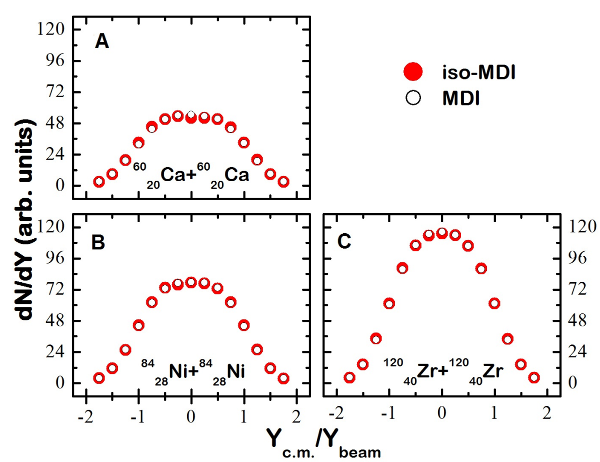

Fig. 2: The rapidity distribution (dN/dY) of nucleons as a function of reduced rapidity for the central collisions of $^{60}_{20}Ca +^{60}_{20} Ca$ (A), $^{84}_{28}Ni +^{84}_{28} Ni$ (B), and $^{120}_{40}Zr +^{120}_{40} Zr$ (C) due to MDI and iso-MDI

Here E(i) and $p_z(i)$ are, respectively, the total energy and longitudinal momentum of the *i*-th particle. Naturally, for a full equilibrium, one should get a Gaussian shaped distribution peaked at the mid-rapidity region. As the nuclear stopping is the phenomenon which is mostly generated from the participant zone, we display the dN/dY as a function of reduced rapidity for various neutron-rich systems in Fig. 2. The single Gaussian curve for the two MDI signify the larger stopping of the nuclear matter but the nuclear stopping is insensitive towards the iso-MDI for the various neutron rich systems.

Summary

From the above discussion, it can be concluded that iso-MDI marginally affects the maximum density and maximum temperature for the systems with different isotopic contents. This motivation will help to further investigate the role of iso-MDI on the other observables for the nuclear matter under extreme conditions.

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References

1. Aichelin J (1991) Quantum molecular dynamics a dynamical microscopic n-body approach to investigate fragment formation and the nuclear equation of state in heavy ion collisions *Phys Rep* **202** 233
2. Cooper ED *et al*. (1987) Global optical potentials for elastic p+ Ca scattering using the Dirac equation *Phys Rev* **C36** 2170
3. Dhawan JK, Dhiman N, Sood AD and Puri RK (2006) From fusion to total disassembly: Global stopping in heavy-ion collisions *Phys Rev* **C74** 057901
4. Hartnack C *et al*., (1998) Modelling the many-body dynamics of heavy ion collisions: Present status and future perspective *Eur Phys J* **A1** 151
5. Hong B *et al*., (1998) Stopping and radial flow in central $^{58}Ni+^{58}Ni$ collisions between 1A and 2A GeV *Phys Rev* **C57** 244
6. Khoa DT *et al*., (1992) In-medium effects in the description of heavy-ion collisions with realistic NN interactions *Nucl Phys* **A548** 102
7. Kumar S, Kumar S and Puri RK *et al*., (2008) Medium mass fragment production due to momentum dependent interactions *Phys Rev* **C78** 064602
8. Liu JY, Guo WJ, Xing YZ and Lee XG (2005) Isospin momentum-dependent interaction and its role on the isospin fractionation ratio in intermediate energy heavy ion collisions *Chin Phys Lett* **22** 65

9. Vermani YK, Goyal S and Puri RK (2009) Momentum dependence of the nuclear mean field and multifragmentation in heavy-ion collisions *Phys Rev* **C79** 064613
10. Vinayak KS and S Kumar (2012) Thermalization and temperature reached in heavy-ion collision using the isospin-dependent quantum molecular dynamics model *Eur Phys J* **A48** 96
11. Vinayak KS *et al*., (2013) Role of isospin momentum dependent interactions in multifragmentation *Proc of the DAE Symp on Nucl Phys* **58** 336.