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Influence of Isospin Dependence of Radius on Fragmentation

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Based on the Isospin dependent Quantum Molecular Dymanics (IQMD) model, we study the influence of isospin dependence of nuclear charge radii on fragmentation for the reaction of $^{120}_{50}Sn +^{120}_{50} Sn$ at an incident energy between 50 and 400 MeV/nucleon. Simulations have been carried out for isospin independent nuclear charge radii (proposed in liquid drop model) and isospin dependent nuclear charge radii (proposed by Royer and Rousseau) parameterizations. Our study reveals that fragmentation is influenced by the isospin dependence of nuclear charge radii and the influence varies with the mass of the fragment.

Key Words : Fragmentation; IQMD; Nuclear Radius; Isospin; Heavy Ion; Symmetric Collisions

Introduction

The nuclear charge radii is one of the fundamental property which is useful to study the characters of nucleus like binding energy, nuclear shapes etc. For a long time, based on the experimental fact that the volume of nucleus is roughly proportional to the number of nucleon (A) and saturation property of the nuclear forces, it was assumed that the nuclear charge radius has the form:

$$R_{LDM} = r_o\, A^{1/3}; where\; r_o = 1.12fm, \tag{1}$$

which was proposed by liquid drop model (LDM) (Bohr and Mottelson, 1969) also called $A^{1/3}$ law. Later on, the root mean square (rms) radius of nucleus is determined by highly precise elastic electron-nucleus and muon-nucleus scattering experiments. $A^{1/3}$ law reveals that the radius of isobaric nuclei is same but experimental results in Ref. (Angeli and Marinova, 2013) proves that the rms (root mean square) radii of

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isobaric nuclei is not same, they differ significantly. The experimentally found rms radii deviate from the radius calculated via $A^{1/3}$ law. Therefore, LDM radius is not valid for nuclei in which number of protons (Z) and neutrons (N) differ significantly. In order to have the modification over the LDM radii, various parameterizations of nuclear charge radii have been proposed in the last 3-4 decades (Ngo and Ngo, 1980; Pomorska and Pomorski, 1994; Royer and Rousseau, 2009). Various studies exist in the literature that demonstrate the importance of nuclear radii in the reaction dynamics throughout the energy range (Fang *et al.*, 2011). Some of the nuclear radii parameterizations have the different radii for protons and neutrons, thus have explicit isospin dependence in them. The nuclear charge radius depends upon the isospin parameter $I = (N - Z)/A$ because of the difference in size and deformation of the proton and neutron density distribution. Various parameterizations have been proposed with additional I term in $A^{1/3}$ dependence of nuclear charge radii in order to obtain a single parameterized form which could be able to reproduce experimental findings of rms radii of all nuclei. The recent isospin dependent parameterized form of nuclear charge radius is proposed in (Royer and Rousseau, 2009) which is labelled by R_{RR} and reads as:

$$R_{RR} = 1.2332A^{1/3} + \frac{2.8961}{A^{2/3}} - 0.18688A^{1/3}I. \qquad (2)$$

This form is more precise and able to reproduce experimental charge radius of nuclei and also gives good accuracy of nuclear charge radii. The introduction of the ground state deformation depending on the distance of Z and N to the proton and neutron magic numbers can still improve the expression. In literature, few studies are available to observe the structural effects via nuclear charge radii on the reaction dynamics in heavy ion collisions at intermediate energy regime. Recently, Bansal *et al.*, (Bansal *et al.*, 2013) studied the role of nuclear charge radii on the collective transverse flow and the energy of vanishing flow (EVF). A strong dependence of nuclear charge radius has been found. In another study (Gautum, 2013), the role of structural effects via nuclear charge radii has been observed in reaction dynamics for isobaric pairs on transverse flow and multifragmentation. Motivated by the above results, we hereby aim to study the role of isospin dependence of nuclear charge radii i.e. R_{RR} and its comparison with R_{LDM} in fragmentation. The present study has been carried out using Isospin dependent Quantum Molecular Dynamics (IQMD) (Hartnack *et al.*, 1998) model.

Results and Discussions

We have simulated thousands of events for the reaction of ${}^{120}_{50}Sn + {}^{120}_{50}Sn$ $(N/Z = 1.4)$ at incident energy between 50 and 400 MeV/nucleon for central collisions. A soft equation of state has been implemented along with 10% reduced isospin dependent nucleon-nucleon (nn) cross-section i.e. $\sigma = 0.9\sigma_{nn}^{free}$. The clusterization has been done by using minimum spanning tree (MST) (Vermani and Puri, 2009) method and reaction is followed till 200 fm/c. Fig. 1 displays the time evolution of the mean multiplicity of free nucleons (FN's) $[A = 1]$ (Fig.1 (A)), light mass fragments (LMF's) $[2 \leq A \leq 4]$ (Fig.1 (B)), medium mass fragments (MMF's) $[5 \leq A \leq 9]$ (Fig.1 (C)) and intermediate mass fragments (IMF's) $[5 \leq A \leq 40]$ (Fig.1 (D)) at an incident energy of 200 MeV/nucleon, because at this energy, the mean field and n-n collisions both contributes towards the reaction dynamics.

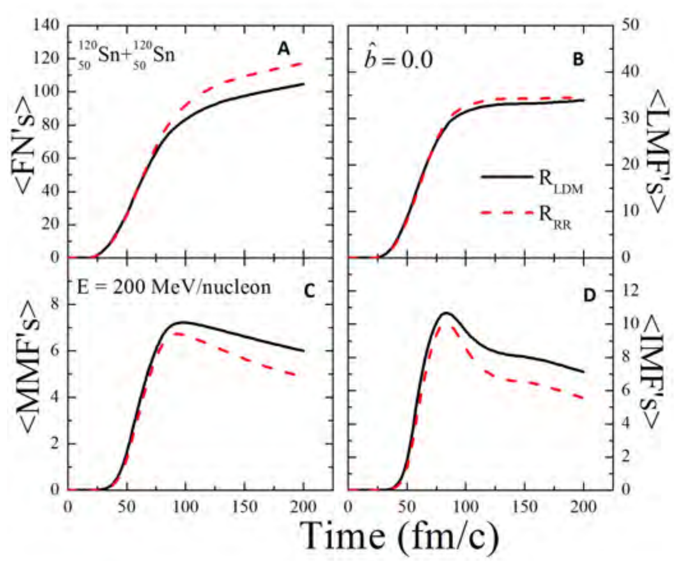

Fig. 1: The time evolution of the mean multiplicity of (A) FN's $[A = 1]$, (B) LMF's $[2 \leq A \leq 4]$, (C) MMF's $[5 \leq A \leq 9]$ and (D) IMF's $[5 \leq A \leq 40]$ for the reaction of $^{120}_{50}Sn +^{120}_{50} Sn$ at an incident energy of 200 MeV/nucleon for central collisions

The different lines in figure corresponds to different parameterizations of nuclear charge radii proposed in Ref. (Bohr and Mottelson, 1969; Royer and Rousseau, 2009). It has been observed that, the calculated radii for the ${}_{50}{}^{120}Sn$ nucleus is 5.524 via R_{LDM} and is 6.0481 via R_{RR}. Therefore due to different formalizations, there is 9.5% increase in the charge radius of $^{120}_{50}Sn$ nuclei and this change in the geometry has a remarkable influence on the production of fragments in heavy ion collision at intermediate energies. It has been observed from Fig. 1, the role of isospin dependent radius is negligible up to time 100 fm/c in the production of various fragments and then increases gradually up to 200 fm/c, which is typical time span of heavy ion collisions. That means initialization effects via nuclear charge radii is negligible at initial state of the reaction and it affects the fragment production at final state of nuclear reaction at intermediate energies because of change in the geometry. The change in the radius or geometry at initial state affects the collision dynamics and final state production of fragments.

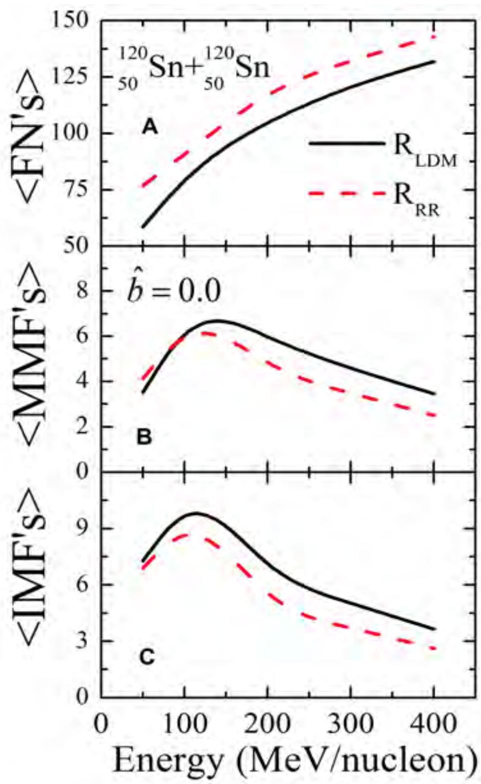

Fig. 2: The incident energy dependence of the mean multiplicity of (A) FN's $[A = 1]$, (B) MMF's $[5 \leq A \leq 9]$ and (C) IMF's $[5 \leq A \leq 40]$ for the reaction of ${}_{50}{}^{120}Sn +{}_{50}{}^{120} Sn$ for central collisions at 200fm/c

At 200 fm/c, the isospin dependence of nuclear charge radii enhance the multiplicities of FN's and LMF's by 12% and 2% respectively. Whereas, the multiplicities of IMF's and MMF's has been reduced by 22% and 20% respectively. That means the isospin dependent radii parameterization results in more destruction of nuclear matter at extreme conditions due to which increase in the multiplicity of smaller fragments have been observed compared to heavier fragment. It is worth to notice that, role of isospin dependent nuclear charge radii parametrization in percentage change of multiplicity is more on heavier fragment as compared to lighter fragments. This happens because, lighter fragments are produced by participant zone and due to violent phase of collisions there is lesser effect on multiplicity via nuclear charge radii whereas, heavy fragments originate from the spectator zone, where the collision rate is small and the change in radii affect the spectator zone as well as multiplicity of heavier fragments.

In Fig. 2, we display the incident energy dependence of final state mean multiplicity of FN's (Fig. 2A), MMF's (Fig. 2B) and IMF's (Fig. 2C). Both the curves shows similar trends. The change in the multiplicity of FN's due to isospin dependent nuclear charge radii is in equal proportion to R_{LDM} with incident energy. Though this effect is almost negligible for MMF's and IMF's at low incident energies, it increases up to 200 MeV/nucleon and remains almost same till 400 MeV/nucleon. Therefore, one can see that the heavier fragments are more sensitive towards isospin dependent nuclear charge radii with incident energies.

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