Role of model ingredients in the fragmentation of asymmetric colliding nuclei in heavy-ion collisions

[1]Arun Sharma, [2]Rohit Kumar, [3]Arun Bharti, [4]Rajeev K. Puri
[1]Assistant Professor, [2]Post Doc. Fellow, [3]Professor, [4]Professor
[1]Department of Physics, G.D.C, Thannamandi, Rajouri, Jammu-185212, India
[2]Department of Physics, Panjab University, Chandigarh-160014, India
[2]Department of Physics, University of Jammu, Jammu-180006, India
[4]Department of Physics, Panjab University, Chandigarh-160014, India
[1]arungaur.ju@gmail.com,[2]rohits708@gmail.com, [3]abharti_2003@yahoo.com, [4]rkpuri@pu.ac.in

ABSTRACT

We investigate the role of momentum-dependent interactions on the fragmentation of asymmetric colliding nuclei using isospin-dependent quantum molecular dynamics model. In particular, we study both central and peripheral collisions of $^{40}Ar+^{64}Cu$, $^{40}Ar+^{108}Ag$ and $^{40}Ar+^{197}Au$. Our investigations reveal significant role of momentum-dependent interactions on the fragmentation pattern in asymmetric colliding nuclei. The relative role of different model ingredients changes depending on the asymmetry of the colliding pair.
Keywords: Multifragmentation, Isospin-dependent quantum Molecular dynamics model, momentum-dependent interactions.

INTRODUCTION

The disassembly of colliding nuclei into various fragments is a complex phenomenon that depends essentially on the reaction inputs such as incident energy, colliding geometry (i.e., impact parameter), system mass, isospin and mass asymmetry of the reaction [1–13] etc. At lower incident energies, the available excitation energy is too small to allow the breaking of nuclei into fragments. But as the incident energy increases, colliding nuclei can disintegrate into dozens of fragments consisting of light charged particles as well as intermediate and heavy mass fragments [1–13]. The evolution of these different fragments (and their sizes) depends on the above mentioned reaction parameters. For example, the total multiplicity of most of the fragments increases with energy. The yield of intermediate mass fragments, however, shows a rise and fall behaviour with incident energy [5, 6, 8–10]. Similarly, extensive studies can be found in the literature where role of system mass and isospin asymmetry has been reported in the fragmentation of various symmetric reactions [3,7, 8]. In addition to above reaction parameters, fragmentation has also been influenced by various physical parameters such as nuclear equation of state (NEOS) [1, 9,13] and/or nucleon-nucleon (nn) scattering cross section [5,11,12]. For example, in Ref. [1], the fragmentation of $^{197}Au+^{197}Au$ reaction was analyzed within quantum molecular dynamics (QMD) approach using soft and hard equations of state and marginal effect of equation of state was reported on multifragmentation. In another study [9], significant effect of EOS as well as its momentum dependence was observed in peripheral collisions of various (nearly) symmetric reactions. It should be noted that Puri *et al*. investigated the role of momentum-dependent interactions, nn cross sections and other model ingredients on the fragmentation in asymmetric reactions of $^{16}O+^{80}Br/^{108}Ag$ [11]. However, this study was limited to central collisions only and moreover, was carried out using isospin independent version of molecular dynamics approach i.e., quantum molecular dynamics (QMD) model [13]. In the present study, we will restrict ourselves to study the influence of static (soft) equation of state as well as its momentum dependence on the fragmentaion of asymmetric reactions at central and peripheral colliding geometry. The current study has been performed using isospin-dependent quantum molecular dynamics (IQMD) model, the details of which can be found in Ref. [14].

RESULTS AND DISCUSSIONS

To address the role of momentum-dependent interaction in asymmetric heavy-ion collisions, we simulated thousands of events for the reactions of $^{40}Ar+^{64}Cu$ (η = 0.23), $^{40}Ar+^{108}Ag$ (η =0.46), $^{40}Ar+^{197}Au$ (η = 0.66) using soft and SMD equations of state, over a wide range of incident energy between 17 and 400 MeV/nucleon, where "η" is the mass asymmetry (= $[A_T - A_P] / [A_T + A_P]$; A_T / A_P are the masses of the target/projectile). In Fig. 1, we display the size of heaviest fragment $\langle A_f^{max} \rangle$ (top panels) and yields of light charged particles LCPs $[2 \le A_f \le 4]$ (middle panels) and intermediate mass fragments IMFs $[5 \le A_f \le 38]$ (bottom panels) for the central collisions of $^{40}Ar+^{64}Cu$, $^{40}Ar+^{108}Ag$ and $^{40}Ar+^{197}Au$ as a function of beam energy using soft (S) and soft momentum-dependent (SMD) equations of state. We find that addition of momentum-dependent interactions lead to reduced $\langle A_f^{max} \rangle$ because of additional breaking of correlations among nucleons. The difference in the size of $\langle A_f^{max} \rangle$ is quite visible at lower beam energies. On the other hand, at very high beam energies, one sees almost same size of $\langle A_f^{max} \rangle$ with soft as well as with SMD equations of state. This is due to the fact that correlations at higher beam energies are already broken due to frequent binary collisions and therefore, additional momentum-dependent interactions don't play any significant role. We also see that momentum-dependent interactions play enhanced role in reactions having higher mass asymmetry; the size of $\langle A_f^{max} \rangle$ reduces by $\sim$ 50% (at lower beam energies) in $^{40}Ar+^{197}Au$ whereas, an approximate 35% reduction in $\langle A_f^{max} \rangle$ is observed in the reaction of $^{40}Ar+^{64}Cu$. This happens because of comparatively less compression in highly asymmetric reaction of $^{40}Ar+^{197}Au$ and thus momentum-dependent interactions break the correlations among interacting nucleons, which on the other hand, have already been broken to some extent due to significant overlapping in less asymmetric reaction of $^{40}Ar+^{64}Cu$. Following these trends of $\langle A_f^{max} \rangle$, the corresponding multiplicities of LCPs and IMFs get enhanced when one uses momentum-dependent interactions.

Next, we will study the effect of momentum-dependent interaction in the dynamics of asymmetric reactions at peripheral collisions. In Fig. 2, we display the size of heaviest fragment and multiplicities of LCPs and IMFs for the reactions of $^{40}Ar+^{64}Cu$, $^{40}Ar+^{108}Ag$ and $^{40}Ar+^{197}Au$ at peripheral collisions using soft and soft momentum-dependent equations of state. The results are quite different than those observed for central colliding geometries (Fig. 1). In contrast to central collisions, where soft and soft momentum-dependent equations of state lead to same $\langle A_f^{max} \rangle$ at higher beam energies, we observe a significant difference in the size of heaviest fragment (and thus various mass fragment's multiplicities) even at higher beam energies; with SMD equation of state yielding smaller $\langle A_f^{max} \rangle$. This is because of the fact that the frequency of nucleon-nucleon collisions at peripheral geometry reduces significantly leading to far less excited matter compared to central collisions where frequent nucleon-nucleon collisions disassemble the colliding nuclei. Therefore, the significant role of momentum-dependent

ISSN: 2229-6913(Print), ISSN: 2320-0332(Online), Web Presence: http://ijoe.vidyapublications.com

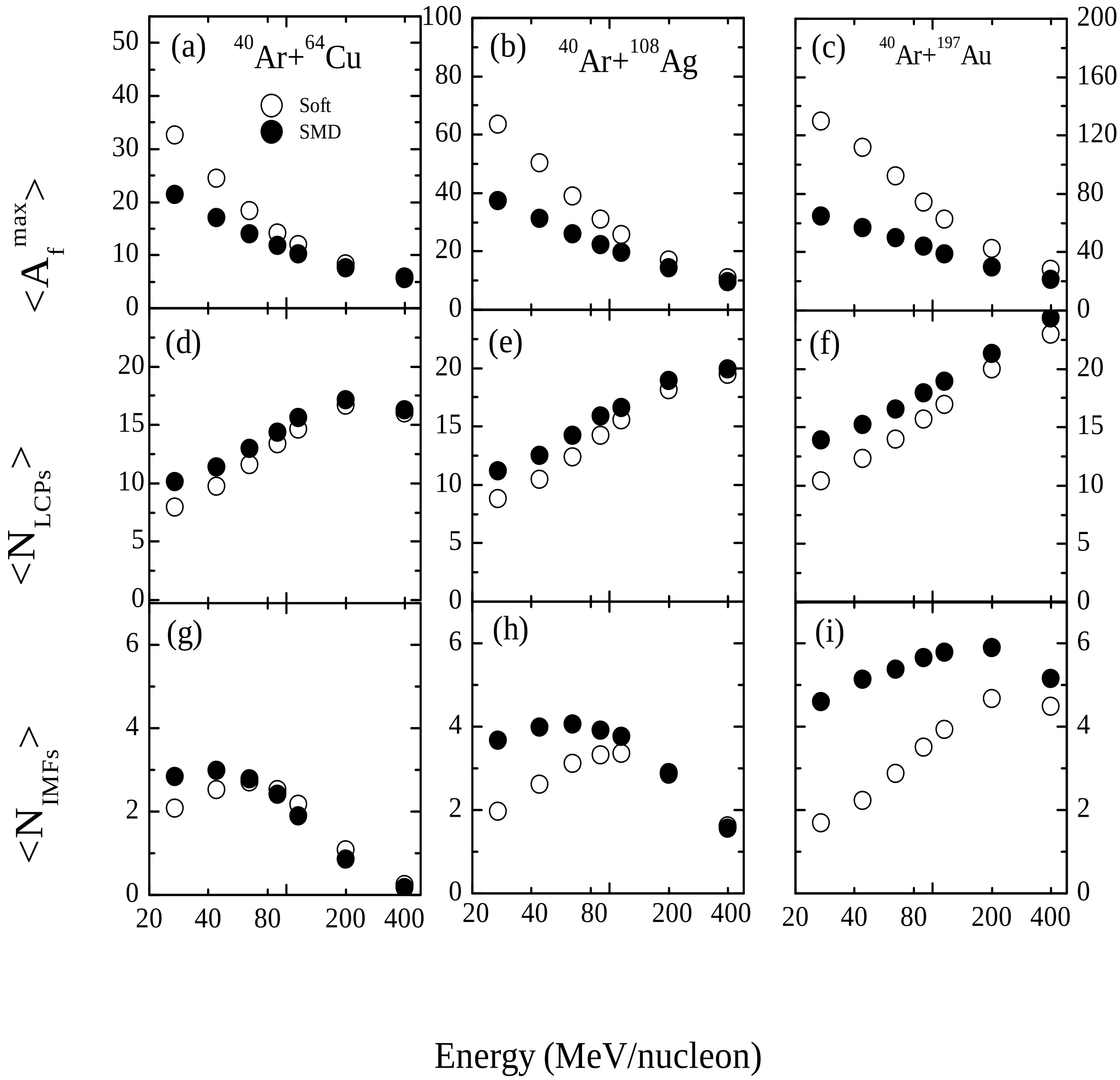

Figure -1. The size of heaviest fragment $<A_f^{max}>$ and multiplicities of light charged particles (LCPs) and intermediate mass fragments (IMFs) as a function of beam energy in the central collisions of $^{40}Ar+^{64}Cu$, $^{40}Ar+^{108}Ag$ and $^{40}Ar+^{197}Au$. Open (solid) symbols represent the results using soft (SMD) equation of state.

interactions even at higher incident energies is because of the reduced compression at these geometries. The additional destruction of initial correlations happens due to inclusion of momentum-dependent interactions.

Under these circumstances, momentum-dependent interactions play a significant role in breaking colliding nuclei into pieces. Similar observations of enhanced role of momentum-dependent interactions at peripheral collisions have also been observed in the dynamics of transverse flow[14]. We also notice that the size of $<A_f^{max}>$ first decreases with beam energy, reaches a minimum and then a further increase is observed at very high beam energies contrary to a monotonic decrease noted in central collisions. This unusual behavior of $<A_f^{max}>$ at peripheral collisions of asymmetric reactions is also reflected in multiplicities of light

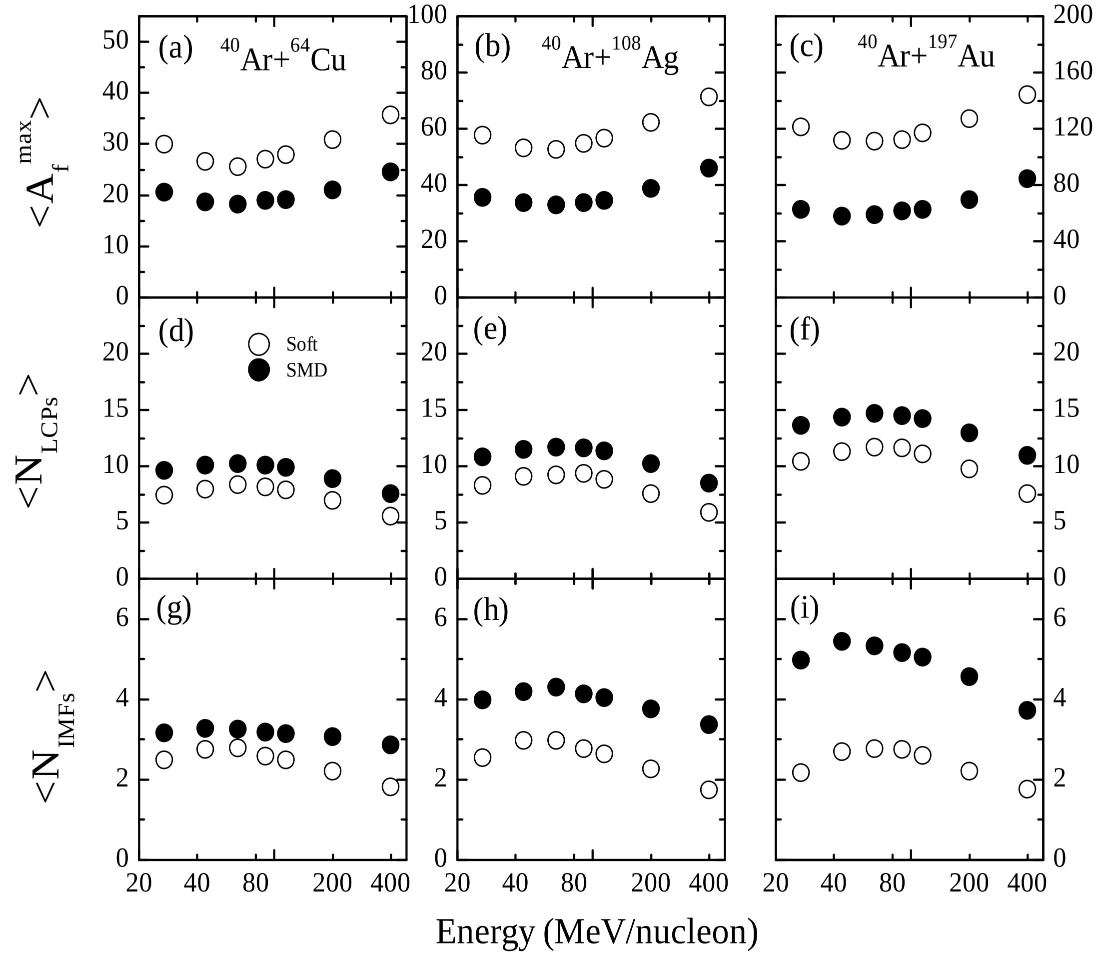

Figure – 2. Same as Figure. 1, but at peripheral collisions.

charged particles where a rise and fall is observed, contrary to central ones (monotonic rise is observed).

SUMMARY

We have presented a detailed analysis on the role of model ingredient such as equation of state on the dynamics of fragmentation involving asymmetric colliding pairs. Our analysis revealed significant effect of this physical parameter on the multifragmentation of asymmetric reactions and the relative behaviour is found to depend on the mass asymmetry of the colliding pair.

REFERENCES

[1] A. Bohnet. and Aichelin J., "Multifragmentation near the threshold", Physical Review C, Volume No.44, Issue No. 5, July 1990.

[2] Kumar S. and Puri R. K., "Stability of fragments formed in the simulations of central heavy ion collisions", Physical Review C, Volume No. 58, Issue No. 5, March 1998.

[3] Goyal S. and Puri R. K., "Formation of fragments in heavy-ion collisions using a modified clusterization method", Physical Review C, Volume No. 83, Issue No. 4, April 2011.

[4] Goyal S. and Puri R. K., "Fragment distributions for highly charged systems", Physical Review C, Volume No. 55, Issue No. 4, May1995.

[5] Sharma A., Bharti A., Gautam S. and Puri R. K "Multifragmentation of nearly symmetric and asymmetric reactions within a dynamical model", Nuclear Physics A, Volume No.945, Pages 95-111, Oct. 2015.

[6] Sharma A. and Bharti A. "Isospin effects via Coulomb forces on the onset of multifragmentation in light and heavily charged systems", EPJA, Volume No.52, Issue No. 42, January 2016.

[7] Singh J. and Puri R. K., "Isospin effects on the energy of peak mass production", Physical Review C, Volume No. 85, Issue No. 1, January 2013.

[8] Sisan D. et al., "Intermediate mass fragment emission in heavy-ion collisions: Energy and system mass dependence ", Physical Review C, Volume No. 63, Issue No. 02, January 2001.

[9] Goyal S., Vermani Y.K. and Puri R. K., "Momentum dependence of the nuclear mean field and multifragmentation in heavy-ion collisions ", Physical Review C, Volume No. 79, Issue No. 6, June 2009.

[10] Kumar R., Gautam S. and Puri R. K., "Influence of different binding energies in clusterization approach: fragmentation as an examples ", Journal of Physics G, Volume No. 43, Page No. 025104, January 2016.

[11] Singh J. Kumar S. and Puri R. K., "Model ingredients and multifragmentation in symmetric and asymmetric heavy ion collisions ", Physical Review C, Volume No. 62, Issue No. 4, October 2000.

[12] Kumar S., Puri R. K. and Aichelin J, "Different nucleon-nucleon cross sections and multifragmentation ", Physical Review C, Volume No. 58, Issue No. 3, September 1998.

[13] Aichelin J, "Quantum Molecular Dynamics- A Dynamical Microscopic n-body approach to investigate fragmentation formation and the nuclear equation of state in heavy-ion collisions", Physics Reports, Volume No. 202, Pages 233-360, 1991.

[14] Hartnack Ch., Puri R.K., Aichelin J., Konopka J., Bas S.A., Stocker H. and Greiner W. "Modelling the many-body dynamics of heavy ion collisions: Present status and future perspective", EPJA, Volume No.51, Pages 151-169, 1998.

ISSN: 2229-6913(Print), ISSN: 2320-0332(Online), Web Presence: http://ijoe.vidyapublications.com