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Research Article

Dependence of Nuclear Flow on Different Parts of Nuclear Interaction Potential

Varinderjit Kaur

G.S.S.D.G.S. Khalsa College, Patiala-147001, Punjab, India.
ORCID:0000-0002-3357-4444
Email:drvarinderjit@gmail.com(corresponding author)

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ABSTRACT:
Background: During a heavy ion reaction, the interaction between projectile and target nucleons takes place and the outcome of a reaction depends strongly on the nuclear interaction potential, which is the imperative factor in deciding the fate of reaction. Several efforts have been made in this direction to explore number of phenomena. One of the most sought after phenomena in this direction is the collective flow and its various forms.
Purpose: This study aims to investigate the dependence of collective nuclear flow on different parts of nucleon-nucleon interaction potential for different mass asymmetric reactions ^{129}Xe + ^{124}Sn (η = 0), ^{82}Kr + ^{158}Gd (η = 0.3), ^{56}Fe + ^{184}W (η = 0.5) and ^{35}Cl + ^{205}Tl (η = 0.7) by keeping A_{total}= 240 units. Two different signatures of collective flow have been studied: a) bounce-off of compressed matter in the reaction plane called directed flow and b) squeeze-out of the participant matter out of the reaction plane called elliptical flow.
Methods: The present work is carried out within the Isospin dependent Quantum Molecular Theoretical Framework in which total interaction potential is composed of Skyrme potential, Yukawa Potential, Coulomb Potential, Momentum dependent interaction potential and symmetry potential.
Results: The findings reveal that the directed flow increases with addition of momentum dependent interactions and symmetry potential while the elliptical flow tend to decrease with addition of these potentials.
Conclusions: Both the momentum dependent interaction potential and symmetry potential have sizable affect on the magnitude of collective nuclear flow. A comparison between our calculations and experimental data for the energy dependence of elliptical flow for $^{129}_{50}$Xe + $^{124}_{50}$Sn reaction reveals that all the components of nuclear potential are necessary to explain the reaction dynamics.

Keywords: Nuclear interaction potential, Nuclear flow, Mass asymmetry, Momentum dependent potential, Symmetry potential.

1. Introduction

The heavy ion (HI) collisions are the eloquent tool to probe the nuclear matter under the extreme conditions of temperature and density in terrestrial laboratory. Several efforts, during past decades, have been made to study the thermodynamic properties of this matter and to shed light on dynamics of its formation and subsequent disintegration [1]. Among different observables, the collective motion of particles in HI collisions has been a topic of interest since it gives physical insight into the dynamical evolution of compressed and hot nuclear matter. It is depicted by the space-momentum correlations which are of dynamic origin, which are explored via study of directed and elliptical flow.The directed flow also called in-plane flow and the elliptic flow also called out-of-plane flow are two different components widely studied in HIC at intermediate energies [2, 3] .

If the beam direction is along z-axis and impact parameter is along x-axis, then x-z plane is defined as reaction plane and x-y plane as azimuthal plane, characterizing the azimuthal distribution of particles. Consider ϕ is the azimuthal angle between the reaction plane and transverse momenta of emitted particles, then the flow can be represented mathematically as

Fourier expansion [4, 5], given as:

$$\frac{dN}{d\phi} = 1 + 2\sum_{n=1}^{\infty} v_n \cos(n\phi) \quad (1)$$

where v_n, the flow parameter, is called nth harmonic function or Fourier coefficient of Fourier expansion where, n = 1, 2, 3 . . . and so on. The first two harmonics, v_1 and v_2 are the directed flow and elliptical flow, respectively. The directed and elliptical flow are defined as:

$$v_1 =< \cos\phi >=< \frac{p_x}{p_t} >; \quad (2)$$

$$v_2 =< \cos 2\phi >=< \frac{p_x^2 - p_y^2}{p_t} > \quad (3)$$

where p_x is the transverse momentum gained by the emitted particle and p_t is the mean transverse momentum given by, $p_t = \sqrt{p_x^2 + p_y^2}$, where p_x and p_y being the x and y components of momentum. The elliptical flow gives the elliptical distribution of outgoing particles in the reaction plane [6, 7]. The positive value of v_2 portrays the in-plane emission of particles while the negative values of v_2 describes the squeeze-out in direction perpendicular to the reaction plane. Several experimental collaborations such as FOPI, INDRA are involved in the study of elliptical flow ranging from Fermi to ultra-relativistic energies [8, 9]. At low energies, the directed flow observables are closely connected to interplay between mean field and nucleon-nucleon collisions and evolves with energy [10]. The elliptical flow arises from expansion of compressed participant zone, which is possibly affected by shadowning effect of spectator matter [11].

The dependence of collective flow on different factors such as colliding geometry, radii of nuclei, projectile energy, mass of colliding nuclei, isospin has divulged stimulating physics involving origin of collective flow and its properties [12, 13, 14]. The study of excitation function of collective flow shows it is negative at low energies as the interaction is governed by attractive component of mean field. But at higher energies, in addition to mean field the repulsive nucleon-nucleon (NN) interactions become significant, resulting in deflection of emitted particles in direction of incident projectile i.e. positive angles. This continuous evolution of flow with increase in energy from negative to positive becomes zero at a particular value of energy, coined as balance energy(E_{bal}), where the attractive mean field is counter balanced by repulsive NN interactions. These studies revealed the strength of transverse flow and E_{bal} which facilitate to probe the nuclear equation equation of state (NEOS) and in-medium NN cross-sections [15, 16, 17].

Many researchers have made efforts in the literature to investigate the mechanism behind heavy ion collisions and multi fragmentation employing the NN interaction potential [18, 19, 20], but the contribution of different parts of NN interaction potential towards collective flow needs further investigation. Therefore we intend to investigate the dependence of collective flow and reaction dynamics on different parts of NN interaction potential in mass asymmetric collisions.

In section 2, brief methodology of the dynamical approach used to interpret experimental results is presented. Results are discussed in section 3. Finally, the conclusions are presented in section 4.

2. Method and Materials: Theoretical Framework

The present work is carried out within the Isospin dependent Quantum Molecular Theoretical Framework [21, 22], a modernized version of the QMD model developed by Aichelin and co-workers [23, 24, 25, 26]. The IQMD model has been used successfully to explain various phenomena such as fragmentation [27, 28], collective flow [29, 30], elliptical flow [31] successfully. The isospin degree of freedom enters into the calculations via symmetry potential, cross-sections and Coulomb interactions. In IQMD model, the nucleons of target and projectile interact via two and three-body Skyrme forces, Yukawa potential and Coulomb interactions. In addition to the use of explicit charge states of all baryons and mesons, a symmetry potential between protons and neutrons corresponding to the Bethe-Weizsacker mass formula has been included. In this model, baryons are represented by wave packet

$$f_i(\vec{r},\vec{p},t) = \frac{1}{(\pi\hbar)^3}\cdot e^{-(\vec{r}-\vec{r}_i(t))^2/2L}\cdot e^{-(\vec{p}-\vec{p}_i(t))^2 2L/\hbar^2}. \quad (4)$$

The centroids of these wave packets propagate using classical Hamilton equations of motion:

$$\frac{d\vec{r}_i}{dt} = \frac{d\langle H\rangle}{d\vec{p}_i} \;;\; \frac{d\vec{p}_i}{dt} = -\frac{d\langle H\rangle}{d\vec{r}_i} \quad (5)$$

with

$$\begin{aligned}\langle H\rangle &= \langle T\rangle + \langle V\rangle \\ &= \sum_i \frac{p_i^2}{2m_i} + \sum_i\sum_{j>i}\int f_i(\vec{r},\vec{p},t)V^{ij}(\vec{r}\,',\vec{r}) \\ &\quad \times f_j(\vec{r}\,',\vec{p}\,',t)d\vec{r}d\vec{r}\,'d\vec{p}d\vec{p}\,' \quad (6)\end{aligned}$$

The baryon-baryon potential V^{ij}, in the above relation, reads as:

$$\begin{aligned}V^{ij}(\vec{r}\,'-\vec{r}) &= V^{ij}_{Skyrme} + V^{ij}_{Yukawa} + V^{ij}_{Coul} + \quad (7)\\ &\quad V^{ij}_{sym} + V^{ij}_{MDI} \\ &= t_1\delta(\vec{r}\,'-\vec{r}) + t_2\delta(\vec{r}\,'-\vec{r})\rho^{\gamma-1}\left(\frac{\vec{r}\,'+\vec{r}}{2}\right) \\ &\quad + t_3\frac{exp(-|\vec{r}\,'-\vec{r}|/\mu)}{(|\vec{r}\,'-\vec{r}|/\mu)} + \frac{Z_iZ_je^2}{|\vec{r}\,'-\vec{r}|} \\ &\quad + t_4\frac{1}{\varrho_0}T_3^iT_3^j\delta(\vec{r}\,'-\vec{r}) \\ &\quad + t_5 ln^2[t_6(\vec{p}\,'-\vec{p})^2+1]\delta(\vec{r}\,'-\vec{r}) \quad (8)\end{aligned}$$

Here Z_i and Z_j denote the charges of i^{th} and j^{th} baryon. The parameters μ and $t_1, ..., t_6$ are adjusted to the real part of the nucleonic optical potential. This interaction potential basically consists of different parts, viz."density-dependent Skyrme potential, repulsive Coloumb potential, Yukawa surface potential, momentum-dependent interaction potential and symmetry potential". The Skyrme is the basic potential that corresponds to the nuclear matter density. The inclusion of Yukawa term improves the surface properties of nuclei, and is considered important for fragment formation. The Coulomb potential comes into picture in case of charged particles and thus, contribute towards the repulsive interaction between protons. Since these interactions are absent for neutrons, so this potential, sometimes, has also been treated as a part of isospin effects which differentiate the protons from neutrons. Likewise, the role of momentum-dependent potential (usually at high incident energies) during initial phase of a collision is established as well, when relative momentum between projectile and target nucleons is high [32]. Lastly, nuclear symmetry potential plays a significant role in nuclear collisions involving isospin (neutron-proton) asymmetric colliding partners. Thus, every term in NN interaction potential is important and plays significant role depending upon entrance channel parameters. However, there is a significant impact of these potential's on fragment production and collective flow at intermediate energies. The term "flow" is usually understood as a phenomenological description of a collective expansion, and the theoretical models are quite successful in describing the observed features of the experimental data available in the literature.

3. Results and Discussions

In the present work, several thousand events have been simulated for the semi-central collisions of the reactions ^{129}Xe + ^{124}Sn (η = 0), ^{82}Kr + ^{158}Gd (η = 0.3), ^{56}Fe + ^{184}W (η = 0.5) and ^{35}Cl + ^{205}Tl (η = 0.7) at incident energies between 50 to 200 MeV/nucleon. In order to study the role of mass asymmetry of the reaction on collective flow, the reactions are chosen in such a way that the mass asymmetry of the reactions varies between 0 to 0.7 while the total mass remains constant i.e. A_{total} = 240 units. A soft equation of state has been employed in present work and the observations are recorded at saturation time (i.e. 200 fm/c) because after this time, there is no further change in the phase space configuration of colliding nuclear matter.

To study the contribution of each component of nuclear interaction potential in different observables, one starts with the basic potential and then resimulate the reaction each time by adding gradually the other components of nuclear potential. Acronym SY stands for Skyrme + Yukawa potential, SYC stands for Skyrme + Yukawa + Coulomb potential, SYCM stands for Skyrme + Yukawa + Coulomb + momentum dependent potential, SYCMS stands for Skyrme + Yukawa + Coulomb + momentum dependence + symmetry potential and SYCMSd stands for Skyrme

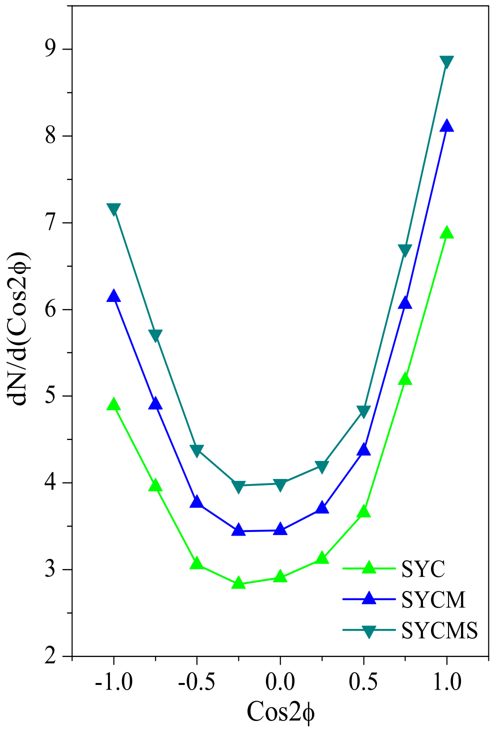

Figure 1: Azimuthal angle dependence of dN/d(Cos2ϕ) for Z = 2 at E = 50 MeV/nucleon for different set of potentials for ^{129}Xe+^{124}Sn reaction. The minima occurring at 2ϕ = π/2 depicts the prominence of in-plane emission whereas the peaks at 2ϕ = 0 and π correspond to the preferred azimuthal emission in-plane and out-of-plane respectively.

+ Yukawa + Coulomb + momentum dependence + density dependent symmetry potential with γ = 0.66.

We begin with the azimuthal dependence of dN/d(Cos2ϕ) for Z = 2 particles at E = 50 MeV/nucleon for ^{129}Xe+^{124}Sn reaction for different set of potentials as shown in Fig. 1. It is clear that minima occurs at 2ϕ = π/2 depicting the prominence of azimuthal emission in-plane whereas the peaks at 2ϕ = 0 and π corresponds to the preferred azimuthal emission in-plane and out-of-plane. Moreover, the peak at 2ϕ = 0 is higher in comparison to at 2ϕ = π, which indicates that number of particles emitted in-plane are large as compare to the number of particles emitted out-of-plane. This means that ellipse formed is not symmetric around the z-axis i.e in the collision of asymmetric nuclei the distribution of nucleon after the collision in momentum space is not uniform. Also, we note that with addition of MDI and symmetry potential, these peaks become more pronounced due to an increase in pressure gradient in overlapping zone resulting due to additional repulsion generated by these potentials. Fig.2 shows

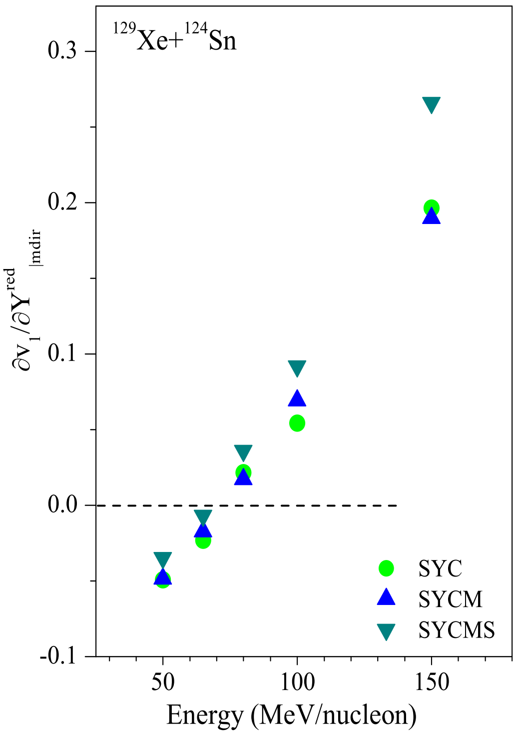

Figure 2: Energy dependence of reduced flow $\partial v_1/\ \partial Y^{red}$ at $\hat{b}$ = 0.5 fm for different set of potentials for ^{129}Xe+^{124}Sn reaction.

the energy dependence of reduced flow in mid-rapidity region, where the nuclear matter compressibility is greater than the spectator region, for ^{129}Xe+^{124}Sn reaction. At low energies, due to Pauli blocking the NN collisions are blocked and mean field dominate the reaction dynamics leading to negative slope of reduced flow at low energies. But with an increase in energy, the dominance of NN collisions increases and hence slope rises. We note that with involvement of MDI and symmetry potential, the reduced flow rises more sharply since these potentials provide extra repulsion to the system.

Further, to illustrate the role of different parts of NN potential in elliptical flow, energy dependence of elliptical flow per nucleon for different asymmetric reactions ^{129}Xe + ^{124}Sn (η = 0), ^{82}Kr + ^{158}Gd (η = 0.3), ^{56}Fe + ^{184}W (η = 0.5) and ^{35}Cl + ^{205}Tl (η = 0.7) is shown for different set of potentials. Fig. 3 shows

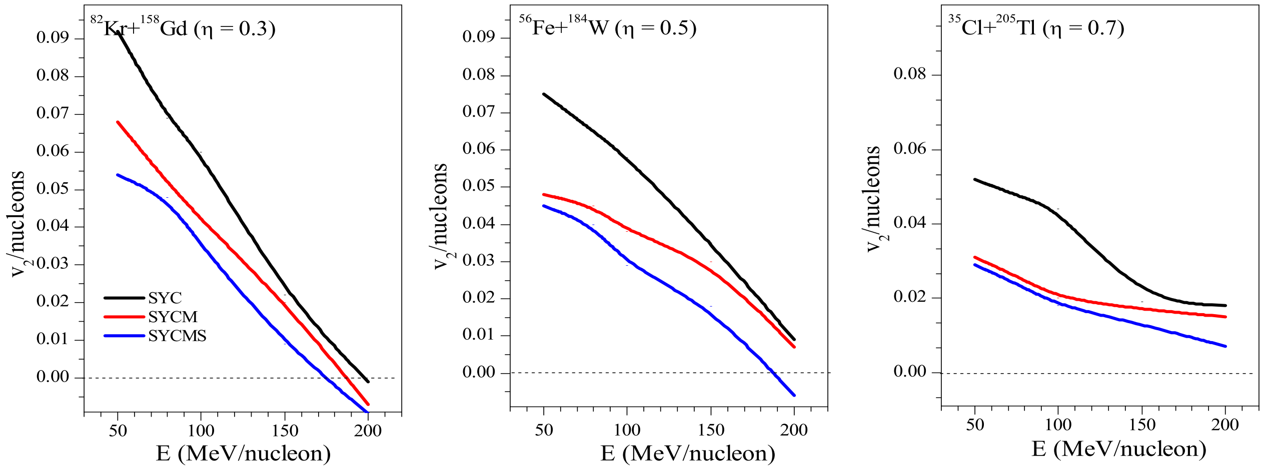

Figure 3: Energy dependence of v_2/nucleon for ^{82}Kr+^{158}Gd (η = 0.3), ^{56}Kr+^{184}W (η = 0.5) and ^{35}Cl+^{205}Tl (η = 0.7) reactions.

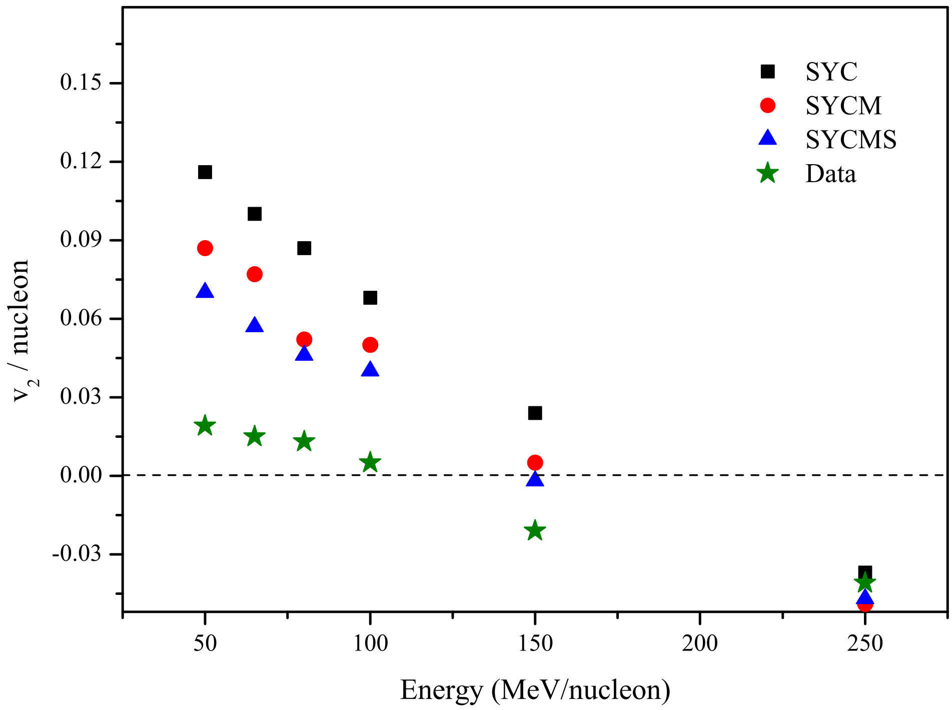

Figure 4: Energy dependence of elliptic flow v_2/nucleons for Z = 2 at $\hat{b}$ = 0.5 fm for different set of potentials for ^{129}Xe+^{124}Sn reaction along with comparison with experimental data.

that the elliptical flow per nucleon (v_2/nucleon) changes from positive to negative values with an increase in energy. As we move from nearly symmetric reaction (η = 0.3) to highly asymmetric reaction (η = 0.7), the trend remains the same while the flow changes to more positive value. It can be associated with change in dominance from mean field at low energies to binary nucleon-nucleon collisions at higher energies. Further, we extend this study to the energy dependence of elliptic flow for symmetric reaction ^{129}Xe+^{124}Sn (η = 0) in reference to available experimental data[34] as shown in Fig. 4. Elliptical flow per nucleon shows a transition from positive to negative values with an increase in energy. The rapidity cut of $Y^{red} = |Y_{c.m.}/Y_{beam}| \leq 0.1$ is in accordance with experimental data. We note that by taking into account both the MDI and symmetry potential, the comparison with experimental data [34] is better. However, at E = 250 MeV/nucleon the role of different parts of potential nearly diminishes due to increase in violence of reaction at higher energies.

4. Findings and Conclusion

The role of different components of nucleon-nucleon interaction potential on collective nuclear flow has been explored by varying the mass asymmetry and keeping A_{total} =240 units fixed, within the theoretical framework. Although the different components of NN potential have remarkable role in fragment production yet the momentum dependent interactions and symmetry potential have sizable affect on the magnitude of collective nuclear flow. The comparison of energy dependence of elliptical flow for $^{129}_{50}$Xe + $^{124}_{50}$Sn reaction with experimental data reveals that all the components of nuclear potential are necessary to explain the reaction dynamics. In future, one can elaborate the influence of density dependent symmetry energy and isospin dependence of NN cross section on the above mentioned observables for highly asymmetric collisions. This can provide a challenge to the experimentalists to prove the theoretical findings. Additionally, colliding lighter projectiles with heavier targets can result in the creation of radioisotopes, which have valuable applications in medical science.

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References

[1] C.K. Gelbke et al., "Dynamical and Statistical Aspects of Intermediate Energy Nucleus-Nucleus Collisions" *Prog. Part. Nucl. Phys.* **19**, 33 (1987). https://doi.org/10.1016/0146-6410(87)90003-2; Google Scholar

[2] M. Abdallah, B. Aboona, J. Adam, et al., "Light nuclei collectivity from sNN = 3 GeV Au + Au collisions at RHIC" *Phys. Lett. B*, **827**, 136941 (2022). https://doi.org/10.1016/j.physletb.2022.136941. Google Scholar

[3] Bo-Gao, Y. Wang et al.,"Elliptic flow in heavy-ion collisions at intermediate energy: The role of impact parameter, mean field potential, and collision term" *Phys. Lett. B*, **838**, 137685 (2023). https://doi.org/10.1016/j.physletb.2023.137685.Google Scholar

[4] S. Voloshin, Y. Zhang, "Flow study in relativistic nuclear collisions by Fourier expansion of Azimuthal particle distributions" *Z. Phys. C* **70**, 665 (1996).https://doi.org/10.1007/s002880050141 Google Scholar

[5] J. Adamczewski-Musch, O. Arnold, C. Behnke, A. Belounnas, et al., "Directed, Elliptic, and Higher Order Flow Harmonics of Protons, Deuterons, and Tritons in Au+Au Collisions at 2.4 GeV" *Phys. Rev. Lett.*, **125**, 262301 (2020). https://doi.org/10.1103/PhysRevLett.125.262301 Google Scholar

[6] J. Y. Ollitrault, "Anisotropy as a signature of transverse collective flow" *Phys. Rev. D* **46**, 229 (1992); H. Sorge, Phys. Rev. Lett. **78**, 2309 (1997). https://doi.org/10.1103/PhysRevD.46.229. Google Scholar

[7] M. Kaur, M. Kaur, and V. Kaur, "Role of different parts of the nucleon-nucleon potential on fragment production in asymmetric collisions and their rapidity dependence" *Phys. Rev. C* **96**, 024626 (2017).https://doi.org/10.1103/PhysRevC.96.024626 Google Scholar

[8] A. Andronic et al., "Excitation function of elliptic flow in Au + Au collisions and the nuclear matter equation of state" *Nucl. Phys. A* **679**, 765 (2001); Phys. Lett. B **612**, 173 (2005).https://doi.org/10.1016/j.physletb.2005.02.060 Google Scholar

[9] J. Lukasik, G. Auger, M.L. Begemann-Blaich et al., "Directed and elliptic flow in 197Au + 197Au at intermediate energies" *Phys. Lett. B* **608**, 223

(2005). https://doi.org/10.1016/j.physletb.2004.12.076 Google Scholar

[10] D.J. Magestro et al., "Disappearance of transverse flow in Au+Au collisions" *Phys. Rev. C* **61**, 021602 (2000). https://doi.org/10.1103/PhysRevC.61.021602 Google Scholar; A. Andronic et al., "Differential directed flow in Au+Au collisions" *Phys. Rev. C* **64**, 041604 (2001). https://doi.org/10.1103/PhysRevC.64.041604 Google Scholar

[11] M.B. Tsang et al., "Multiplicity dependence of azimuthal distributions for 36Ar+197Au collisions at E/A=35 MeV" *Phys. Rev. C* **47**, 2717 (1992). https://doi.org/10.1103/PhysRevC.47.2717 Google Scholar; W.Q. Shen et al., "Disappearance of rotational flow and reaction plane dispersions in Kr+Au collisions" *Phys. Rev. C* **57**, 1508 (1998). https://doi.org/10.1103/PhysRevC.57.1508.Google Scholar

[12] C. A. Ogilvie et al., "Transverse collective motion in intermediate-energy heavy-ion collisions" *Phys. Rev. C* **40**, 2592 (1989). https://doi.org/10.1103/PhysRevC.40.2592. Google Scholar

[13] G. D. Westfall et al., "Mass dependence of the disappearance of flow in nuclear collisions" *Phys. Rev. Lett.* **71**, 1986 (1993). https://doi.org/10.1103/PhysRevLett.71.1986 Google Scholar; D. Klakow, G. Welke, and W. Bauer, "Nuclear flow excitation function" *Phys. Rev. C* **48**, 1982 (1993). https://doi.org/10.1103/PhysRevC.48.1982 Google Scholar

[14] Sangeeta and V. Kaur, "Structural and isospin effects on balance energy and transition energy via different nuclear charge radii parameterizations" *Nuclear Physics A* **966**, 20-33 (2017). https://doi.org/10.1016/j.nuclphysa.2017.05.096 Google Scholar

[15] M. B. Tsang, G. F. Bertsch, W. G. Lynch, and M. Tohyama, "Impact parameter and energy dependence of observables in intermediate energy heavy-ion reactions" *Phys. Rev. C* **40**, 1685 (1989). https://doi.org/10.1103/PhysRevC.40.1685. Google Scholar

[16] A. Le Fèvre, Y. Leifels, C. Hartnack, J. Aichelin "Origin of elliptic flow and its dependence on the equation of state in heavy ion reactions at intermediate energies" *Phys. Rev. C*, **98**, 034901 (2018). https://doi.org/10.1103/PhysRevC.98.034901. Google Scholar

[17] B. A. Li, "In-medium cross section and disappearance of flow" *Phys. Rev. C* **48**, 2415 (1993). https://doi.org/10.1103/PhysRevC.48.2415. Google Scholar

[18] M.Begemann-Blaich, et al., "Quantum molecular dynamics simulation of multifragment production in heavy ion collisions at E/A=600 MeV" *Phys. Rev. C* **48**, 610 (1993). https://doi.org/10.1103/PhysRevC.48.610. Google Scholar

[19] M.B. Tsang, et al., "Fragment multiplicity dependent charge distributions in heavy ion collisions" *Phys. Rev. C* **55**, R557 (1997). https://doi.org/10.1103/PhysRevC.55.R557. Google Scholar

[20] A. Schuttauf et al., "Universality of spectator fragmentation at relativistic bombarding energies" *Nucl. Phys. A* **607**, 457 (1996). https://doi.org/10.1016/0375-9474(96)00239-4 Google Scholar

[21] C. Hartnack, R. K. Puri, J. Aichelin, J. Konopka et al., "Modelling the many-body dynamics of heavy ion collisions: Present status and future perspective" *Eur. Phys. J. A* **1**, 151 (1998). https://doi.org/10.1007/s100500050045. Google Scholar

[22] C. Hartnack, H. Oeschler, Y. Leifels, E.L. Bratkovskaya et al., "Strangeness production close to the threshold in proton–nucleus and heavy-ion collisions" *Phys. Rep.* **510**, 119 (2012). https://doi.org/10.1016/j.physrep.2011.08.004. Google Scholar

[23] J. Aichelin, A. Rosenhauer, G. Peilert, H. Stöcker et al., "Importance of Momentum-Dependent Interactions for the Extraction of the Nuclear Equation of State from High-Energy Heavy-Ion Collisions" *Phys. Rev. Lett.* 58, 1926 (1987). https://doi.org/10.1103/PhysRevLett.58.1926. Google Scholar

[24] J. Aichelin, "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 (1991). https://doi.org/10.1016/0370-1573(91)90094-3 Google Scholar

[25] E. Lehmann, R.K. Puri, A. Faessler, G. Batko et al., "Consequences of a covariant description of heavy-ion reactions at intermediate energies" *Phys. Rev. C* **51**, 2113(1995). https://doi.org/10.1103/PhysRevC.51.2113. Google Scholar

[26] E. Lehmann, R.K. Puri, A. Faessler, T. Maruyama et al., "Relativistic versus nonrelativistic quantum molecular dynamics" *Prog. Part. Nucl. Phys.* **30**, 219 (1993). https://doi.org/10.1016/0146-6410(93)90025-B. Google Scholar

[27] V. Kaur, S. Kumar, "Phase space analysis of fragmentation and the role of mass asymmetry" *Phys. G: Nucl. Part. Phys.* **39**, 085114 (2012). https://doi.org/10.1088/0954-3899/39/8/085114 Google Scholar

[28] S. Kaur, R.K. Puri, "Isospin effects on the energy of peak mass production" *Phys. Rev. C* **87**, 014620 (2013). https://doi.org/10.1103/PhysRevC.87.014620. Google Scholar

[29] A.D. Sood, R.K. Puri, J. Aichelin, "Study of balance energy in central collisions for heavier nuclei" *Phys. Lett. B* **594**, 260 (2004). https://doi.org/10.1016/j.physletb.2004.05.053

Google Scholar

[30] S. Gautam, A.D. Sood, R.K. Puri, J. Aichelin, "Sensitivity of the transverse flow to the symmetry energy" *Phys. Rev. C* **83**, 034606 (2011). https://doi.org/10.1103/PhysRevC.83.034606 Google Scholar

[31] V. Kaur, S. Kumar, R.K. Puri, "On the elliptical flow and mass asymmetry of the colliding nuclei" *Phys. Lett. B* **697**, 512 (2011). https://doi.org/10.1016/j.physletb.2011.02.044 Google Scholar

[32] L. Zhuxia, C. Hartnack, H. St¨ocker and W. Greiner, "Transition from binary processes to multifragmentation in quantum molecular dynamics for intermediate energy heavy ion collisions" *Phys. Rev. C* **44**, 824 (1991). https://doi.org/10.1103/PhysRevC.44.824 Google Scholar

[33] Andreas Ekström "Analyzing the Nuclear Interaction: Challenges and New Ideas" *Frontiers in Physics* **8**, 1-15 (2020). https://doi.org/10.3389/fphy.2020.00029 Google Scholar

[34] N. Herrmann, J.P. Wessels, T. Wienold, "Collective flow in heavy ion collisions" *Annu. Rev. Nucl. Part. Sci.* **49**, 581 (1999). https://doi.org/10.1146/annurev.nucl.49.1.581. Google Scholar; J. Lukasik, W. Trautmann, for the INDRA and ALADIN Collaborations, "Collective flow in heavy ion collisions at intermediate energies" *Proc. International Nuclear Physics Conference (INPC*, (Tokyo 2007) **2**, 513-515 (2007). https://doi.org/10.48550/arXiv.0708.2821. Google Scholar

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