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Structural and isospin effects on balance energy and transition energy via different nuclear charge radii parameterizations

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Abstract

The structural and isospin effects have been studied through isospin dependent and independent nuclear charge radii parameterizations on the collective flow within the framework of Isospin-dependent Quantum Molecular Dynamics (IQMD) model. The calculations have been carried out by using two approaches: (i) for the reaction series having fixed N/Z ratio and (ii) for the isobaric reaction series with different N/Z ratio. Our results indicate that there is a considerable effect of radii parameterizations on the excitation function of reduced flow ($\frac{\partial v_1}{\partial Y^{red}}$) and elliptical flow ($v_2$). Both balance energy ($E_{bal}$) and transition energy (E_{trans}) are enhanced with increase in radii of reacting nuclei and found to follow a power law with nuclear charge radii. The exponent τ values show that the elliptical flow is more sensitive towards different nuclear charge radii as compared to reduced flow. Moreover, we observe that our theoretical calculation of E_{bal} and E_{trans} are in agreement with the experimental data provided by GSI, INDRA and FOPI collaborations.
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1. Introduction

The abstraction of nuclear charge radii parameterization has become a key center in theoretical as well as experimental nuclear structure research for a long time [1–7]. With the development of muonic and electronic scattering experiments, it is easy to find the radius of a particular nucleus [1]. The recent measurements of nuclear radii from $_1$H to $_{96}$Cm (including approximately 909 isotopes) reveals the isotopic as well as the isotonic behavior of nuclear radius [2]. The theoretical studies offer numerous parameterizations of nuclear charge radii conducive to obtain the experimental radii [3–7]. The theoretical studies of low energy nuclear reaction dynamics acknowledges that the use of different forms of nuclear charge radii affect the low density phenomena like fusion barrier, cluster radioactivity, binding energies and neutron skin thickness etc. [7,8]. The nuclear charge radii parameterization is also a topic of interest at intermediate energy heavy ion collisions (HICs) in virtue of sensitivity of theoretical models of this field. In these models, the nuclear charge radii parameterization, which is the first and an essential model ingredient used to construct the nuclear matter, is generally considered to be an isospin-independent quantity. However, in the present day, we have the isospin-dependent forms of nuclear charge radii. Now it is crucial to know that, how the nuclear reaction dynamics at intermediate energy regime will be affected if one considers the isospin-dependent nuclear charge radii parameterization to initialize the nucleus.

1.1. Collective flow

In literature, the depiction of collective flow has attained much interest and attention because of its ability to elaborate the properties of strongly interacting and thermally excited nuclear matter at intermediate energies [9–12]. The knowledge about the isospin physics through collective flow is important not only for the phenomenalistic understanding of the properties of isospin-asymmetric nuclear matter, but also for astrophysical concepts like surface properties of neutron-star and supernova explosion etc. [13]. The pressure gradient developed during collisions, pushes the nuclear matter away from the interacting region and towards the transverse direction which is basically the azimuthal distribution of particles [14]. If two nuclei are approaching to each other parallel to the z-axis and impact parameter is parallel to the x-axis, then the x–z plane is the reaction plane and x–y plane is the azimuthal plane, which describes the azimuthal distribution of particles. Let ϕ be the azimuthal angle between the trajectory of outgoing particles and the reaction plane such that the distribution of particles in the azimuthal plane can be represented by Fourier expansion [15], reads as:

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

The flow parameter v_n is called nth harmonic function or Fourier coefficient of Fourier expansion where, $n = 1, 2, 3 \ldots$ and so on. The first two harmonics, v_1 and v_2 are the directed flow and elliptical flow respectively. The parameter of directed flow is further expressed as the ratio of transverse momentum gained by the emitted particle, i.e. p_x (along the impact parameter direction) to the mean transverse momentum (p_t) given by, $p_t = \sqrt{p_x^2 + p_y^2}$ where, p_x and p_y are the x and y components of momentum. The directed flow is defined as:

$$v_1 = \ < Cos\phi > \ = \langle \frac{p_x}{p_t} \rangle. \quad (2)$$

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