Role of different NN potentials and densities in the description of heavy-ion fusion

Shilpa Rana[1], Raj Kumar[1], and M. Bhuyan[2]
[1]*Department of Physics and Materials Science,*
Thapar Institute of Engineering and Technology, Patiala-147004, Punjab, India and
[2]*Institute of Physics, Sachivalaya Marg, Bhubaneswar 751005, Odisha, India*

Introduction

The study of the heavy-ion fusion in the low energy regime leads to a better understanding of several physical phenomena such as the nature of nuclear forces, nucleosynthesis of heavy elements in various astrophysical environments, synthesis and characteristics of exotic nuclei and the correlation between the nuclear structure and reaction dynamics. As the exact nature of nuclear forces remains elusive, the formulation of nuclear potential contributing to the short-ranged attractive part of the total interaction potential formed between two colliding heavy-ions is still fuzzy. Consequently, the myriad phenomenological, macroscopic, semi-microscopic and microscopic models have been developed in the literature to describe nuclear interaction potential formed between two fusing nuclei [1].

The double folding approach [2] is one of the well-adopted approaches for the study of heavy-ion fusion. In general, the nuclear densities obtained using the 2-parameter Fermi (2pF) along with the Paris and Reid versions of M3Y (Michigan 3 Yukawa) effective NN interactions are used as inputs in the double folding model [3]. In recent studies [2], the nuclear densities and R3Y NN interactions obtained within the well-known relativistic mean-field (RMF) formalism have also been utilized to calculate nuclear potential within the double folding approach for the description of heavy-ion fusion. In the present study, we aim to study the impact of different effective NN interactions and nuclear densities on the mechanism of heavy-ion fusion. For this, we have considered both the Reid and Paris versions of the well-known M3Y NN interaction along with the relativistic R3Y NN interaction for the non-linear NL3* parameter set. Moreover, the nuclear densities for the interacting nuclei are obtained using the 2pF formula and the RMF-NL3* formalism. These NN potentials and densities are further used to obtain the cross-section within the ℓ-summed Wong model [2] for the illustrative case of ^{16}O+^{154}Sm reaction.

Theoretical Formalism

Within the double folding approach, the nuclear potential formed between a spherical projectile quadrupole deformed target nuclei can be written as,

$$V_n(\vec{R},\beta_2,\theta_2) = \int \rho_p(\vec{r}_p)\rho_t(\vec{r}_t(\beta_2,\theta_2)) V_{eff}\Big(|\vec{r}_p - \vec{r}_t + \vec{R}| \equiv r\Big) d^3r_p d^3r_t. \quad (1)$$

The densities of the interacting projectile ($\rho_p(\vec{r}_p)$) and target ($\rho_t(\vec{r}_t)$) and effective NN potential (V_{eff}) are the requisite inputs for the calculation of nuclear potential within the double folding approach. Here, the nuclear densities are obtained using the 2pF formula [3] supplemented with the values of half-density radius and the surface diffuseness parameters from the experimental electron scattering data. The results of the 2pF densities are compared with the densities obtained within the self-consistent RMF formalism for the non-linear NL3* parameter set. The quadrupole deformation β_2=0.267 for ^{154}Sm is obtained within the RMF formalism in the axially deformed harmonic-oscillator basis for the non-linear NL3* parameter set and its impact is further included in the description of target densities through the nuclear radius in terms of spherical harmonics [2]. The deformed 2pF and RMF-NL3* densities are folded with three different NN potentials namely the non-relativistic Reid and Paris M3Y NN potentials (named as RM3Y and PM3Y, respectively) and the relativistic R3Y NN interaction. The nuclear potentials obtained using different nuclear densities and NN potentials are further used to obtain the fusion barrier characteristics at different target orientation angles (θ_2) and the θ_2-integrated cross-section within the ℓ-summed Wong model [2].

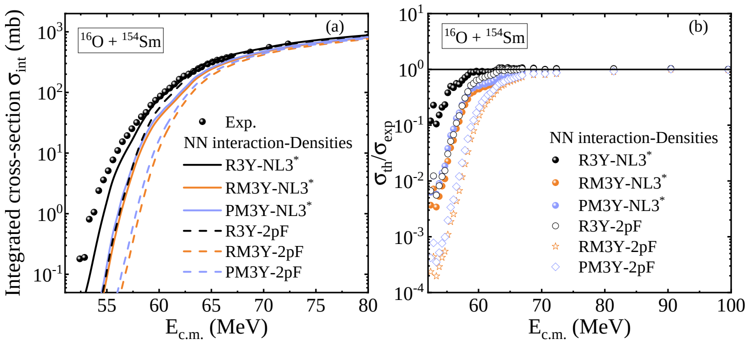

FIG. 1: (a) The total integrated cross-section σ_{int} (mb) obtained using the R3Y, RM3Y and PM3Y NN potentials folded with nuclear densities obtained from RMF-NL3* and 2pF approaches. (b) Ratio of calculated cross-sections (σ_{th}) and experimental cross-section (σ_{exp}) taken from [4]

Results and Discussion

Figure 1(a) shows the θ_2-integrated cross-section calculated using the R3Y (black lines), RM3Y (orange lines) and PM3Y (blue lines) folded with the RMF-NL3* (solid lines) and 2pF (dashed lines) densities. Here, the relativistic R3Y NN potential is noted to provide a higher cross-section in the sub-barrier energy region as compared to the non-relativistic Reid and Paris M3Y NN effective NN interactions. This is because the relativistic R3Y NN potential which includes the mesons degrees of freedom in the description of effective NN interaction gives comparatively attractive nuclear potential and consequently, a lower fusion barrier than the M3Y NN interactions. Moreover, the Paris version of the M3Y NN potential gives a slightly higher sub-barrier cross-section than the Reid-M3Y NN potential. On comparing the cross-section obtained using different densities, it is observed that the microscopic RMF-NL3* gives a higher sub-barrier cross-section than the phenomenological 2pF densities. On comparing the theoretical cross-sections calculated using different NN potentials and densities with the experimental data from [4], the R3Y NN potential folded with RMF densities obtained RMF formalism is noticed to provide a comparatively better match with the experimental data at sub-barrier energy regions. Further, the cross-sections obtained using different approaches are noted to overlap at the above barrier energies due to the dominance of angular momentum over the nuclear structure effects.

For a more systematic and quantative analysis, the ratio of calculated cross-sections (σ_{th}) for different nuclear potentials and experimental cross-section (σ_{exp}) taken from [4] is plotted as the functions of center of mass energies ($E_{c.m.}$) in Fig. 1(b). The R3Y-NL3* and RM3Y-2pF are observed to give the lowest and highest deviation from the experimental cross-section for the considered reaction, respectively. However, these observations might vary for other reactions since the results of 2pF densities depend upon the choice of radius and surface diffuseness parameters. Also, the slight underestimation of the sub-barrier cross-section noted for R3Y-NL3* can be attributed to the higher order deformations of ^{154}Sm nucleus, which are not taken into account here. All these observations infer that the NN potential and nuclear densities encapsulate crucial information about the internucleon interactions and nuclear structural properties in the description of heavy-ion fusion. Thus, the reliable choice of these inputs becomes necessary to study heavy-ion fusion, especially for reactions leading to the formation of exotic nuclei such as superheavy nuclei. A more comprehensive study to explore the role of different NN potentials and densities in descriptions of heavy-ion fusion of target-projectile combinations from different mass regions will be communicated shortly.

References

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