Fusion dynamics of heavy and superheavy nuclei within the relativistic mean field formalism

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Introductions: At low energy, till now a plenty of information on fusion dynamics is available in the literature through experiments and theories. Theoretically, it is suggested that below the Coulomb barrier, the nuclear structure effects dominate the resulting fusion dynamics, whereas the centrifugal potential suppresses the structure effects at/above barrier energies. Further, the shape degrees of freedom of two fusing system also play role on fusion hindrance over the saddle point. In this connection, it is necessary to introduce the microscopic nature of the heavy ion reaction, namely, the relativistic mean-field treatment of nucleus-nucleus optical potential. In other words, in the mean field level, such an optical potential is readily obtained in the double-folding model [1] using the microscopic ground-state densities of the two colliding nuclei (projectile & target) and relativistic nucleon-nucleon (NN) interaction. So far, this kind of nucleus-nucleus optical potential are successfully applied to many nuclear aspects such as nuclear radioactivity, nuclear scattering, nuclear fission and fusion process [2].

Recently, we have introduced a new effective $NN-$interaction entitled R3Y potential [2, 3] analogous to the M3Y form [1], and can be derived from the relativistic mean field Lagrangian, which mainly depends on the relativistic force parameters, the coupling constant among the interacting mesons and their masses [3]. In one of our previous work, we have successfully applied the nonlinear N-R3Y potential for the study of fusion hindrance phenomenon of Ni-based reactions [3]. Hence, it will be of great interest to examine the performance of the N-R3Y potential along with the relativistic mean field density for the study of fusion reaction of even-even, even-odd, and odd-odd systems.

Theoretical Framework To study the fusion hindrance reaction phenomena using the relativistic mean field formalism via ℓ-summed Wong model [4], we need the nuclear density distribution of the interacting nuclei (projectile and target) and the nucleon-nucleon potential. The nuclear density distributions for all projectiles & targets, and the N-R3Y potential are obtained from the relativistic mean field Lagrangian for NL3* parameter set. The nuclear interaction potential V_N (R) between the projectile (p) and target (t) nuclei is calculated by using the well known double folding procedure [1, 3] from respective RMF densities ρ_p and ρ_t for the phenomenological M3Y and recently developed N-R3Y potential. The R3Y potential can be obtained either analytically and/or numerically for any relativistic parameter sets, as it mainly obtains from the mass and coupling constant of the interacting meson fields, where an effective Lagrangian describe the interaction among the nucleons through the effective mesons and electromagnetic fields. It is worth mentioning that the N-

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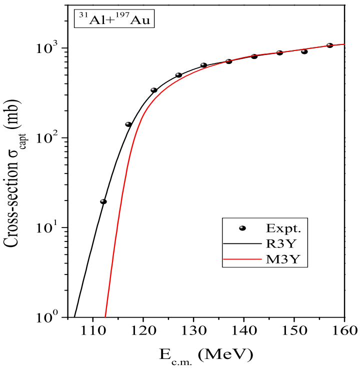

FIG. 1: (Color online) The fusion cross-section for odd-odd ^{31}Al + ^{197}Au system using M3Y and relativistic N-R3Y nucleon-nucleon interaction for NL3* densities within the ℓ-summed Wong model along with the experimental data [6].

R3Y interaction potential is already applied to the radioactivity studies of some highly isospin asymmetry systems using preformed cluster decay model (PCM) [2] and very recently to the fusion hindrance of Ni-based systems [3].

Results and Discussions: The total nuclear interaction potential V_T (R) = V_N + V_C is obtained for even-even, ^{48}Ca + ^{154}Sm, ^{48}Ca + ^{238}U, ^{48}Ca + ^{248}Cm, ^{64}Ni + ^{238}U, ^{26}Mg + ^{248}Cm; even-odd, ^{46}K + ^{181}Ta; and odd-odd ^{31}Al + ^{197}Au, and ^{39}K + ^{181}Ta systems (not given here), where V_N and V_C stands for nuclear and Coulomb potential, respectively. To estimate the fusion reaction cross-section, we need the barrier characteristics, i.e., barrier height, position and frequency, which can be extracted from the total interaction potential of colliding nuclei. The ℓ-summed Wong formula is used to obtain the fusion reaction cross-section for these systems. The ℓ_{max}-values are extracted using the sharp cut-off model [5] for above barrier energies and are extrapolated at lower energies using the above barrier ℓ_{max}-values as a function of center-of-mass energy. In Fig. 1, the solid red and black lines are for the fusion cross-section using relativistic non-linear (N-R3Y) interaction for non-linear NL3* parameter set and phenomenological M3Y potential, respectively for ^{31}Al + ^{197}Au as a representative case. The experimental data [6] are also given for comparison, wherever available.

From the figure, it is observed that N-R3Y performs relatively superior to M3Y interaction in comparison to the experimental data [6] at below barrier energies [7]. The cross-section corresponding to N-R3Y almost overlap to the experimental data except a few cases for energies below the Coulomb barrier whereas the M3Y fits the data only at above barrier energies. The nuclear interaction from N-R3Y potential explain the cross-section reasonably well at comparatively lower energies. It is to be noted that the fusion cross-section corresponding to N-R3Y interaction is always larger as compare to that of M3Y potential. It is observed from all these systems (see Fig. 1) that the N-R3Y interaction is proven to be relatively better choice than M3Y for studying the fusion reactions below the barrier energy. This imply that the N-R3Y interaction allows the nuclei to relax, which reduces the barrier height and hence increases the fusion cross-section.

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