Fusion barrier characteristics of odd-odd, odd-even, and even-even systems using the relativistic mean-field approach

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Introduction

The nuclear fusion reactions have a significant role to probe the various physical phenomena ranging from stellar energy production to extend the Periodic Table [1]. The interaction potential formed between the fusing nuclei is essential to elucidate the nuclear fusion mechanisms. This interaction potential contains three terms: the charge-dependent Coulomb potential, angular momentum-dependent centrifugal potential, and attractive nuclear potential. The Coulomb and centrifugal potentials have well-defined formulae, whereas the nuclear potential term is not fully established. In literature, different phenomenological, semi-microscopic, and microscopic approaches are available for the description of nuclear interaction potential [1].

In the present analysis, we have used the well-established relativistic mean-field (RMF) [2, 3] approach to extract the nuclear potential which is further employed to investigate the fusion characteristics of illustrative cases of odd-odd ^{31}Al+^{197}Au, even-odd ^{46}K+^{181}Ta and even-even ^{48}Ca+^{238}U systems. The effects of nuclear density distributions and the R3Y effective nucleon nucleon (NN) potential obtained for non-linear NL1 and TM1 RMF parameters sets are probed on the fusion barrier characteristics. It is worth mentioning that the TM1 parameter set accounts for the self-interaction of vector mesons in RMF Lagrangian [2]. For comparison, the nuclear potential is also obtained using well-known M3Y NN potential. The fusion/capture cross-section is calculated using the ℓ-summed Wong model, and the results are also compared with the experimental cross-section [4].

Theoretical Formalism

The nuclear interaction potential between the projectile and target nuclei is obtained within the double folding approach [5] i.e.,

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

Here, ρ_p and ρ_t denote the densities for the projectile and target nuclei, respectively. V_{eff} is the effective NN interaction potential. These quantities are obtained from the relativistic mean-field formalism [2, 3] which considers the mesonic degrees of freedom in the microscopic description of interactions between point-like Dirac nucleons. The relativistic R3Y NN potential obtained on solving the RMF equations for point-like mesons is comparable to the phenomenological M3Y potential [3]. More details of RMF formalism, Relativistic R3Y, and M3Y NN potential can be found in [3] and references therein.

The total potential is obtained by adding the Coulomb and centrifugal potential terms to the nuclear potential and is further used to calculate the fusion/capture cross-section within the ℓ-summed Wong model [3]. The fusion/capture cross-section for two colliding nuclei in terms of ℓ -partial wave can be written as [3]

$$\sigma(E_{c.m.})=\frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_\ell(E_{c.m}). \quad (2)$$

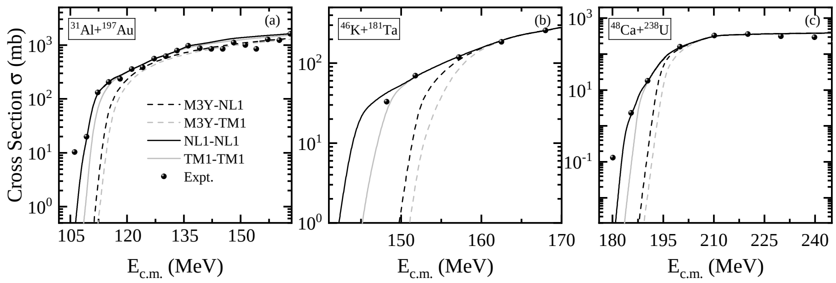

FIG. 1: The cross-section σ (mb) obtained from ℓ-summed Wong model using M3Y (dashed lines) and R3Y (solid lines) interaction. The solid circle indicates the experimental data [4].

TABLE I: The position R_B (in fm) and height V_B (in MeV) of fusion barrier obtained using R3Y and M3Y NN-potential for densities from NL1 and TM1 parameter sets.

System	M3Y-NL1		NL1-NL1		M3Y-TM1		TM1-TM1	
	R_B	V_B	R_B	V_B	R_B	V_B	R_B	V_B
^{31}Al+^{197}Au	12.1	114.193	12.8	108.625	12.0	115.410	12.5	111.108
^{46}K+^{181}Ta	12.3	152.369	13.0	144.604	12.2	153.815	12.7	147.749
^{48}Ca+^{238}U	12.9	193.283	13.6	183.851	12.7	195.106	13.3	187.737

Results and Discussion

The position (R_B) and height (V_B) of the fusion barrier for all the three reaction systems are given in I. Here, M3Y-NL1 and M3Y-TM1 (NL1-NL1 and TM1-TM1) signify that the M3Y (R3Y) NN potential is integrated over RMF densities for NL1 and TM1 parameter sets, respectively, to obtain the nuclear potential. It can be observed from Table I that the R_B shifts towards the higher separation distance whereas the V_B decreases for R3Y potential. Comparing the results obtained for different RMF parameter sets, it is noticed that the TM1 and NL1 parameter sets gives the highest and lowest fusion barriers, respectively. Moreover, the difference between fusion barrier characteristics obtained for different combinations of NN potentials and densities increases with the mass number of the compound nucleus (CN) formed.

The fusion/capture cross-section (σ) obtained from the characteristics of fusion barrier within the ℓ-summed Wong model is shown in Fig. 1 as function of center of mass-energy ($E_{c.m.}$). It can be noted from Fig. 1 that the R3Y NN potential gives a higher cross-section as compared to M3Y potential. Moreover, the NL1 parameter set is observed to yield the highest cross-section, whereas the lowest cross-section is observed for the TM1 parameter set. Comparison of theoretical and experimental cross-section [4] manifest that the NN potential and densities obtained from the NL1 parameter set give a better fit to experimental data than the other combinations. All these observations indicate that the inclusion of vector meson self-coupling in the TM1 parameter set gives a repulsive NN interaction potential and thus decreases the fusion probability. However, the results are preliminary, and a systematic study involving more reaction systems is under process.

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