Proceedings of the DAE Symp. on Nucl. Phys. 66 (2022)

Fusion cross-section using density-dependent relativistic R3Y effective nucleon-nucleon interaction

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Introduction

The investigation of low-energy heavy-ion induced fusion reactions is important to study various aspects of nuclear and astrophysics ranging from the extension of the Periodic Table to the energy generation in stellar environments. The evaluation of nuclear potential formed due to the interaction of two colliding heavy ions is vital to understand the complex fusion dynamics. One of the well-known models to obtain the nucleus-nucleus interaction potential is the double folding approach which gives the nuclear potential in terms of an effective nucleon-nucleon (NN) interaction and nuclear densities [1, 2]. The Paris and Reid M3Y (Michigan 3 Yukawa) interactions have been widely adopted in the double folding model to determine the effective NN potential. Various density-dependent versions of these Paris and Reid M3Y interactions have also been developed to account for the higher-order exchange effects which also result in a better description of infinite nuclear matter characteristics [1].

The R3Y effective NN potential has also been developed within the relativistic mean-field (RMF) approach [2] recently, which is comparable to the density-independent M3Y interaction. The present study aims to introduce the density-dependence in the R3Y NN potential within the Relativistic-Hartree-Bogoliubov (RHB) approach [3] and to apply this density-dependent R3Y (DDR3Y) potential to obtain the fusion cross-section for the illustrative case of the ^{16}O+^{208}Pb reaction.

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Theoretical Formalism

The details of theoretical formalism for obtaining the nuclear potential and cross-section using the RMF densities and R3Y as well as M3Y NN potentials can be found in Ref. [2]. The density-dependent R3Y NN potential ($V_{eff}^{R3Y}(r,\rho)$) in terms of density-dependent nucleon-meson couplings is obtained within the Relativistic-Hartree-Bogoliubov approach for the DDME1 parameter set [3] and can be written as,

$$V_{eff}^{R3Y}(r,\rho) = \frac{[g_\omega(\rho)]^2}{4\pi}\frac{e^{-m_\omega r}}{r} + \frac{[g_\rho(\rho)]^2}{4\pi}\frac{e^{-m_\rho r}}{r} - \frac{[g_\sigma(\rho)]^2}{4\pi}\frac{e^{-m_\sigma r}}{r} + J_{00}\delta(r). \quad (1)$$

Here, all the symbols retain their usual meanings. For further details see Ref. [2]. The density (ρ) entering in Eq. (1) is obtained within the relaxed density approximation (RDA) [2] at the mid-point of the inter-nucleon separation. In DDM3Y interactions, the ρ is generally obtained within the simple frozen density approximation (FDA) [1]. More details of FDA and RDA and their applicability in obtaining the DDM3Y and DDR3Y can be found in [2]. The results of DDR3Y NN potential obtained for the well-known DDME1 parameter set are also compared with the R3Y NN potential obtained for the non-linear NL3* parameter set as well as with the non-relativistic Reid M3Y and BDM3Y1 version of the DDM3Y NN potentials [1].

Results and Discussion

The application of newly developed DDR3Y effective NN interaction in probing the fusion mechanism of ^{16}O+^{208}Pb reaction is dis-

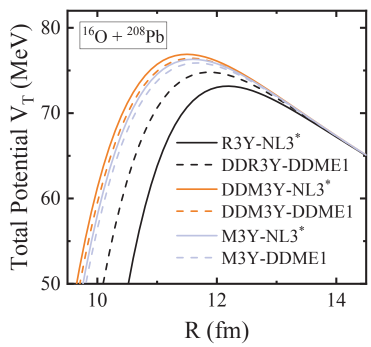

FIG. 1: The total potential V_T (MeV) at $\ell = 0\hbar$ for ^{16}O+^{208}Pb reaction calculated using the M3Y (blue lines), DDM3Y (orange lines), R3Y (solid black line) and DDR3Y (dashed black line) NN potentials.

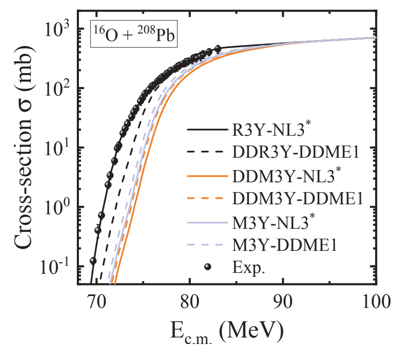

FIG. 2: The cross-section σ (mb) for the ^{16}O+^{208}Pb reaction calculated using the M3Y (blue lines), DDM3Y (orange lines), R3Y (solid black line) and DDR3Y (dashed black line) NN potentials.

cussed in this section. Fig. 1 shows the barrier region of the s-wave ($\ell = 0\hbar$) interaction potential calculated using different nuclear potentials. Here, DDR3Y-DDME1 (dashed black line) signifies the nuclear potential obtained folding the nuclear densities and DDR3Y NN potential in terms of density-dependent nuclear-meson couplings for the DDME1 parameter set. Similarly, R3Y-NL3* signifies (solid black line) the nuclear potential obtained using the densities and relativistic R3Y NN potential for the non-linear NL3* parameter set. The DDME1 (dashed lines) and NL3* (solid lines) densities are also folded with the non-relativistic M3Y (blue lines) and DDM3Y (orange lines) NN potentials. It can be observed from Fig. 1 that the inclusion density-dependence in the R3Y NN potential within the RHB approach raises the fusion barrier with respect to the R3Y NN potential obtained for the non-linear NL3* parameter set. The DDM3Y Reid NN potential is also observed to give a higher fusion barrier as compared to the density-independent M3Y NN potential. Moreover, the DDME1 densities folded with M3Y and DDM3Y NN potentials give a lower barrier than the NL3* densities, whereas this trend gets inverted when folded with the R3Y and DDR3Y NN potentials.

The fusion cross-section σ (mb) obtained for all the six nuclear potentials under consideration is plotted in Fig. 2 as a function of center of mass energies $E_{c.m.}$ (MeV). The theoretical results for the ^{16}O+^{208}Pb reaction are also compared with the experimental data [4]. A decrease in the cross-section is observed on moving from the R3Y NN potentials for the NL3* model to the DDR3Y NN potential given in terms of the density-dependent nuclear-meson couplings for the DDME1 set. Although the DDR3Y NN potential provides a better fit to the experimental data as compared to the M3Y and DDM3Y NN potentials, it underestimates the experimental data at below-barrier energies. However, the nuclear densities and R3Y NN potentials for the non-linear NL3* parameter set give a satisfactory match with the experimental data. A more comprehensive analysis involving more reaction systems from different mass regions is under process.

Acknowledgments

This work has been supported by Science Engineering Research Board (SERB), File No. CRG/2021/001229, FOSTECT Project Code: FOSTECT.2019B.04 and FAPESP Project Nos. 2017/05660-0.

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