Study of the fusion phenomena in heavy ion collisions and the α-decay using nucleon-nucleon interaction derived from relativistic mean field theory

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Introduction

The nucleus-nucleus potential in the study of α-decay and fusion reactions may be obtained by using effective NN interactions, which are remarkably related in the double folding model (DFM) [1]. It is obtained in DFM by using an effective NN interaction, like the phenomenological M3Y plus a zero-range pseudo-potential or a density-dependent M3Y (DDM3Y), folded over the matter densities of the interacting nuclei. Recently, we (Singh and Patra) and collaborators have introduced a microscopic NN interaction (R3Y) [2] from the linear relativistic mean field theory (RMFT) [3] Lagrangian, rather than a simple phenomenological prescription. In the present work, we employ it to investigate the g.s. α-decay of few nuclei in trans lead region and low-energy heavy-ion fusion reactions using two projectile-target systems $^{12}C +^{208} Pb$ and $^{16}O +^{208} Pb$, which have been studied experimentally quite extensively [4], compare our results with that of the use of phenomenological M3Y effective NN interaction, also.

Methodology

Our methodology for the study is to use the linear RMFT(HS) and the barrier penetration model (BPM). The nuclear matter densities are calculated by using the linear RMFT-HS formalism for spherical nuclei. The nucleus-nucleus potentials between the nuclei in the double folding model (DFM) [1] is obtained using an effective NN interaction, like the phenomenological M3Y, given as

$$v_{M3Y}(r) = 7999\frac{e^{-4r}}{4r} - 2134\frac{e^{-2.5r}}{2.5r}, \qquad (1)$$

where ranges are in fm and the strength in MeV, plus a zero-range pseudo-potential ($J_{00}(E)\delta(r)$, EX), folded over the matter densities of the nuclei. A microscopic NN interaction (R3Y) [2] from the linear relativistic mean field theory (RMFT-HS) [3] Lagrangian, obtained as

$$v_{R3Y}(r) = 11956\frac{e^{-3.97r}}{4r} + 4099\frac{e^{-3.90r}}{4r} - 6882\frac{e^{-2.64r}}{4r}. \qquad (2)$$

The Coulomb potential $V_C(R)(= Z_1Z_2e^2/R)$ is calculated for getting the total interaction potential $V(R) = V_n(R) + V_C(R)$ between the nuclei. Further, within the preformed cluster model (PCM) of Gupta and collaborators [5], we deduce empirically the α preformation probability ${P_0}^{\alpha(emp)}$ from experimental data on a few ground state (g.s.) α decays in the trans-lead region. Also, within the barrier penetration model (BPM) we get total fusion cross-sections (σ_{fus}) using the well known Wong formula [6].

Calculations and Discussions

Fig. 1(i) illustrates the total interaction potentials $V(R)$ for α decay of ^{222}Ra, obtained for both the M3Y+EX and R3Y+EX NN interactions using RMF-HS densities. The penetration path with an energy equal to the Q-value of decay is also shown here. Note

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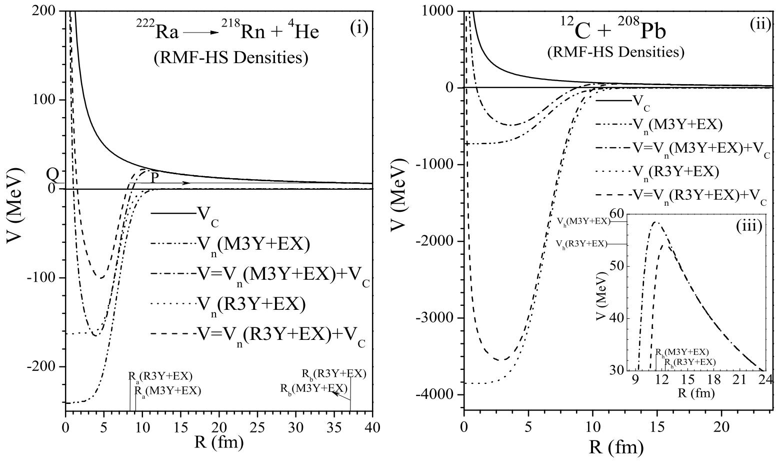

FIG. 1: (i) $V(R)$, the total nucleus-nucleus optical potential and the individual contributions $V_n(R)(R3Y+EX)$ and $V_n(R)(M3Y+EX)$ for HS parameter set, and $V_C(R)$, the Coulomb potential as a function of radial separation R for α-decay of ^{222}Ra. (ii) Same as (i) but for the fusion reaction $^{12}C+^{208}Pb$. (iii) The inset of (ii); same as (ii) but with a changed scale in order to magnify the barrier position (R_h) and the height (V_h).

that, compared to the M3Y NN interaction, the barrier is a bit higher for the R3Y case and hence P decreased. Consequently, the deduced ${P_0}^{\alpha(emp)}(R3Y+EX)$ are also affected. However, we find that the values of ${P_0}^{\alpha(emp)}(R3Y+EX)$ are similar to the ${P_0}^{\alpha(emp)}(M3Y+EX)$.

Fig. 1(ii) illustrates the total interaction potentials $V(R)$ for ^{12}C+^{208}Pb system, obtained for both the M3Y+EX and R3Y+EX NN interactions using RMF-HS densities. The modification of the barrier is also shown here for the two choices. Note that, compared to the M3Y NN interaction, the barrier height is lowered and barrier position increased for the R3Y case (shown more clearly in the inset Fig. 1(iii)). Consequently, the σ_{fus} calculations are also affected. Interestingly, we find that the variation of fusion cross section σ_{fus} as function of energy $E_{c.m.}$ for the $^{12}C+^{208}Pb$ and $^{16}O+^{208}Pb$ systems is quite similar for both the M3Y+EX and R3Y+EX NN interactions in comparison with the experimental data [4], specifically, when the calculated σ_{fus} is reduced by 1.5 times for the choice of R3Y NN interaction. Moreover, we see that the fusion barrier distribution D($E_{c.m.}$) for both the reactions $^{12}C+^{208}Pb$ and $^{16}O+^{208}Pb$ are similar for the M3Y+EX and R3Y+EX NN interactions in comparison with the experimental data [4]. The other details of the present work are presented in the reference [7].

Summary

We have shown in this study that the effective nucleon-nucleon interaction, here called R3Y, derived from the simple linear Walecka Lagragian, can be used to study the g.s. α-decay as well as fusion phenomena in heavy ion collisions rather than using the simple phenomenological prescription, which is presented eloquently in terms of the well known inbuilt RMFT parameters of σ, ω and ρ meson fields.

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