Effect of isospin on fusion reaction cross-section using various nuclear proximity potentials

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Introduction

In the recent years, fusion hinderance phenomena [1] is hot topic of research in nuclear physics. The first explanation of the hindrance phenomena comes from the work of Misicu and Greiner [2]. They use M3Y potential barrier with additional phenomenological repulsive core added to it for filling the pocket of the potential. The repulsive core is shown to modify the inner part of the potential in terms of a thicker barrier and shallower pocket. In a recent work of me and collaborators [3], to study the fusion hindrance, nuclear proximity potential derived for Skyrme nucleus-nucleus interaction in semiclassical extended Thomas Fermi approach, using the Skyrme energy density formalism is used with in the extended-Wong model for fitting of the Ca- and Ni-induced reactions and found that reactions are force dependent. In that work only the GSkI force, whose parameters were obtained by taking care of isospin, is able to fit the data nicely for ^{64}Ni+^{100}Mo reaction. A similar isospin effect are studied here using various versions of proximity potentials, since these potentials use the surface energy constant γ that depends on isospin in turn. These proximity potentials are tested here for Ni-induced reactions and then a modified version is given that include the appropriate isospin effects. Here various versions of nuclear proximity potential are used with in the Wong model to see the effect of isospin on the fusion cross-section, specially at below the Coulomb barrier energies [4]. In this paper, it is tried to find a particular interaction, with proper isospin effects, which when used in a reliable reaction model, leads to a simultaneous explanation of several reactions displaying hindrance to fusion.

Theory

The nuclear interaction potential, V_N, between two surfaces can be written as:

$$V_N(s_0(T)) = 4\pi\bar{R}\gamma b(T)\phi(s_0(T)), \qquad (1)$$

where $\bar{R}(T)$ is the mean curvature radius and Φ is the universal function.γ is the surface energy coefficient which has two parameters γ_0 and k_s. Different versions of nuclear potentials used here are Proximity 1977 (Prox 1977), Proximity 1988 (Prox 1988), Proximity 2000 (Prox 2000) and modified version of Prox 1988 (mod-Prox 1988) [4]. In mod-Prox 1988, the value of coefficient γ_0, used for Prox 1988, i.e. 1.2496 MeV.fm^{-2} is slightly adjusted to 1.65 MeV.fm^{-2} and rest is same as the Prox 1988 including universal function.

Wong Model

The fusion cross-section is calculated using the Wong formula and its extended version. According to Wong [5], the fusion cross-section for two deformed and oriented nuclei, colliding with $E_{c.m.}$, is

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

Wong applied some approximations on Eq. (2) and finally derived a simple formula,

$$\sigma(E_{c.m.},\theta_i) = \frac{{R_B^0}^2\hbar\omega_0}{2E_{c.m.}} \ln\left[1+\exp\left((2\pi/\hbar\omega_0)(E_{c.m.}-V_B^0)\right)\right], \qquad (3)$$

which on integrating over the orientation angles θ_i gives the fusion cross-section. Eq. (2) is denoted as extended-Wong model and Eq. (3) is the well known Wong formula.

Calculations and Results

Fig. 1(a-c) shows that Prox 1988 (red-dashed line) performing well with in Wong formula, specially for the below barrier energies where as the other two are weaker (solid line for Prox 1977 and dotted line for Prox 2000). So Prox 1988 is then used with in the extended-Wong model in which complete ℓ-effects are considered. It is clear from the Top panel of Fig. 1 that for Prox 1988 with in the extended-Wong model gives nice fitting to the data except for the reaction ^{64}Ni+^{100}Mo (see Fig. 1 (c); case of asymmetric colliding nuclei). Fig. 1(d-f) shows the variation of deduced ℓ_{max} with $E_{c.m.}$. Also the point noted here is that though Prox 1988 (blue-dashed line), with in the extended-Wong model, gives nice fit for the cross-sections for the reactions ^{58}Ni+^{58}Ni and ^{64}Ni+^{64}Ni yet the variation of ℓ_{max} (cross-dashed line) at lower energies is not smooth (see Fig. 1(d) and (e)). At below barrier energies for ^{64}Ni+^{100}Mo, ℓ_{max} is deduced by summing the contribution of all ℓ-values that contribute to the cross-section (for detail of summation see Ref. [6]). Thus further a strong nuclear proximity potential, which takes care of adequate isospin effect and asymmetry of colliding nuclei, is needed. So

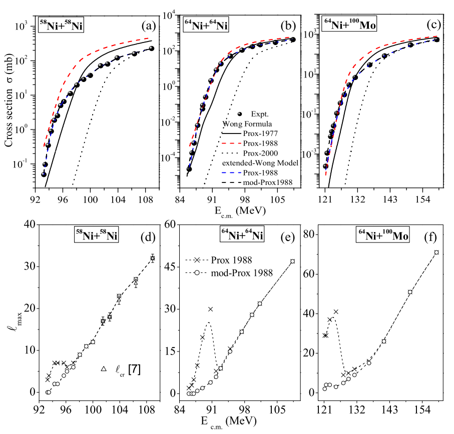

FIG. 1: Top panel: Comparison of fusion-evaporation cross-sections for Ni-induced reactions, calculated from the Wong formula and extended-Wong model for various version of proximity potentials, with the experimental data [1, 7, 8]. Bottom panel: The deduced ℓ_{max} for same reactions but for Prox1988 and mod-Prox 1988 within the extended Wong model.

in order to account for the fusion-evaporation cross-section at energies below the barrier, with smooth variation of ℓ_{max}, the isospin dependence of proximity potential, Prox 1988, is slightly adjusted by modifying the coefficient of nuclear surface energy constant (γ_0) from 1.2496 to 1.65 $MeV.fm^{-2}$, resulting in more stronger and attractive nuclear potential named as mod-Prox 1988. This adjustment cause appreciable change in the barrier characteristics (the barrier height, its position, as well as the oscillator frequency). It is clear from Fig. 1(a-c) that this modified version of Prox 1988 (dashed line) gives nice fit to all the three Ni-induced reactions with deduced $\ell_{max}(E_{c.m.})$, as shown in Fig. 1(d-f) (hollow circle-dashed line), varying smoothly, achieving zero value at the sub-barrier energies and have a tendency to saturate at the above-barrier energies. It is be noted in the Bottom panel of Fig. 1 that deduced ℓ_{max}-values are same for both the proximity used at above barrier energies but varies differently for the below barrier energies, hence clearly showing a strong effect of isospin at below barrier energies. Also, the ℓ_{max} values, shown in Fig. 1 (d), compare nicely with the critical angular momentum ℓ_{cr} deduced from experimental data [7] for ^{58}Ni+^{58}Ni reaction at higher $E_{c.m.}$'s. Hence concluding, isospin plays as important role for fusion reaction cross-section specially at below barrier energies.

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