Role of spin-orbit interaction and Skyrme forces in Ni-induced reactions

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Introduction

The fusion of two nuclei is possible if the projectile is assumed to penetrate through the potential barrier between two interacting nuclei and form a composite nucleus. The shapes of colliding nuclei are also very important in the reaction dynamics. Deformation of one or both the colliding nuclei strongly enhance the fusion cross section. The interaction potential between two nuclei consists of the attractive short range nuclear potential, the Coulomb repulsive interaction, and the centrifugal term. The Coulomb and centrifugal terms are well understood whereas there are large ambiguities in the nuclear part. Several microscopic and analytical nuclear interaction potentials are available in literature.

In the present work, we use the Skyrme nucleus-nucleus interaction in the semiclassical extended Thomas fermi (ETF) approach, under frozen density approximation [1]. The nuclear potential is obtained as a sum of the spin-orbit density-dependent V_J part and spin-orbit density-independent V_P part of the Skyrme Hamiltonian density. With in the ETF approach, it is of interest to study the variation of spin-orbit part with increase in N/Z ratio of the compound systems. In the following, we carry out this study of the role of spin-orbit density part of interaction potential on nine even-mass compound nuclei (CN) $^{156-172}$Yb* formed in $^{56-72}$Ni+^{100}Mo reactions where both spherical and deformed nuclei are involved. The spin-orbit density interaction potential is obtained by using the Skyrme energy density formalism (SEDF) [2], which has the advantage of introducing the intrinsic barrier modification, if needed, with the use of different Skyrme forces [3].

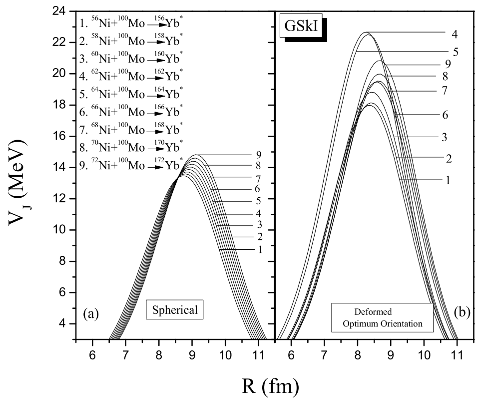

FIG. 1: The spin-orbit interaction potentials for GSkI force, starting from ^{56}Ni+^{100}Mo and increasing neutrons in the projectile beam, taking (a) spherical and (b) deformed nuclei.

Recently, an experiment was performed to measure fusion cross sections of ^{160}Yb*, formed in ^{60}Ni+^{100}Mo [4] over a wide range of incident energies spread across the Coulomb barrier. Therefore, in this paper we use the different Skyrme forces to calculate the fusion excitation function of ^{160}Yb* in order to investigate the performance of these forces, particularly, in below barrier region.

Theory

The total interaction potential is defined as the sum of the deformation and orientation dependent Coulomb, proximity and angular momentum dependent potentials, i.e.,

$$\begin{aligned} V_T^\ell(R) &= V_C(R, Z_i, \beta_{\lambda i}, T, \theta_i) + V_N(R, A_i, \beta_{\lambda i}, T, \theta_i) \\ &\quad + V_\ell(R, A_i, \beta_{\lambda i}, T, \theta_i). \end{aligned} \tag{1}$$

All the terms in Eq. (1) are also T-dependent. Here, we calculate the nuclear proximity potential by using the ETF approach in SEDF.

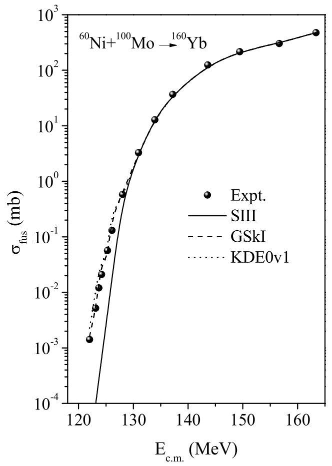

FIG. 2: Fusion excitation function for $^{160}Yb^*$ formed in ^{60}Ni+^{100}Mo, calculated for use of ℓ-summed Wong model (Eq. (3)) for various Skyrme forces, compared with experimental data.

The energy density formalism defines the nuclear interaction potential as

$$V_N(R) = E(R) - E(\infty) \qquad (2)$$

where, $E = \int H(\vec{r})d\vec{r}$ with H as the Skyrme Hamiltonian density. For nucleon densities, we use the two-parameter Fermi distribution, which for the compound system are added under frozen approximation (for details, see Refs. [3, 5]).

The fusion cross-section is calculated by using the ℓ-summed Wong model [6] for deformed and oriented nuclei, colliding with $E_{c.m.}$, given as

$$\sigma(E_{c.m.}) = \int_{\theta_i=0}^{\pi/2} \sigma(E_{c.m.}, \theta_i) sin\theta_i d\theta_i. \qquad (3)$$

Calculations and Results

First, we study the spin-orbit density dependent interaction potential V_J for various isotopes of Yb* by using Skyrme force GSkI, having strong isospin dependence. Further, the role of deformations is studied in reference to change in barrier characteristics. Comparing Fig. 1(a) with 1(b), we notice the following results: (i) For spherical choice of nuclei, the barrier height of V_J increases slowly with increase in number of neutrons and barrier position shifts towards larger interaction radius; (ii) with deformation effect included, compared to the spherical case, the barrier height increases systematically, with a comparatively larger magnitude, with increase in N/Z ratio, i.e., in going from $^{156}Yb^*$ to $^{172}Yb^*$ compound system, except for oblate shaped projectiles ^{62,64}Ni. In other words, the V_J for spherical nuclei exhibits lowest barrier height, which systematically increases for prolate nuclei, and subsequently the oblate shaped nuclei show the highest barrier.

We know from our earlier calculations (Fig. 3 of [3] or Fig. 6 of [5]) that the barrier characteristics are strongly influenced with the change of Skyrme force. The new forces (GSkI, SSk and KDE0v1) include stronger isospin effect with lower barriers whereas old forces (SIII, SKM*) are less sensitive towards isospin effect having higher barriers. Since deformations and use of different Skyrme forces change the barrier characteristics, we study in Fig. 2 the impact of these two properties on the fusion excitation function of ^{60}Ni+^{100}Mo reaction within the framework of ℓ-summed Wong model. Fig. 2 shows that both new forces GSkI and KDE0v1 fit the data nicely, both at above and below the Coulomb barrier energies, compared to old force SIII. Hence, SIII force needs barrier modification [6] in order to fit the data at below barrier energies, which allows us to conclude that a proper choice of Skyrme force is important to address the below barrier data.

References

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