Coupled channel verses EDWSP analysis for the fusion of ^{32}S with ^{112}Sn at sub-barrier energies

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Introduction

Quantum mechanical tunneling plays a very effective role in the different area of physics and tunneling through a potential barrier occurs due to wave nature of particle. Fusion involving heavy-ions in nuclear physics are the examples of multi-dimensional quantum tunneling. In fusion process, the fusion partners with many channel coupling effects tunnel through the nominal barrier and finally fused into a potential pocket to form a compound nucleus. In literature, it was pointed out that the tunneling probability is strongly affected by the internal structure of participants. The coupled channel analysis of distinct fusing pairs suggested that the experimental fusion excitation functions were turned out to be much larger with reference to the outcomes of the one-dimensional BPM [1-2].

In literature, the collective surface excitations of the fusing systems both of static and dynamic in nature, neck formation, zero-pint motion of nuclear surface, and particle transfer channels were identified as dominant intrinsic degree of freedom. To specify the influences of nuclear structure degree of freedom, the coupled channel models were extensively used in literature. In coupled channel analysis, all such dominant intrinsic channels associated with collision pairs are coupled to their relative motion. The coupled channel calculations obtained by incorporating the dominant intrinsic channels are appropriate for the retrieving the experimental data of the fusing partner under study [3-4]. This work makes the use of the EDWSP method [5-15] and coupled channel approach [16] for estimating the fusion cross-section for the ^{32}S + ^{112}Sn system [17].

Theoretical model

In current work, the Woods-Saxon potential is used for the numerical estimations. In the EDWSP model, the potential depth is mathematically defined by Eq. (1).

$$V_0 = \left[A_P^{\frac{2}{3}} + A_T^{\frac{2}{3}} - \left(A_P + A_T\right)^{\frac{2}{3}}\right] \times \left[2.38 + 6.8\left(1 + I_P + I_T\right)\frac{A_P^{\frac{1}{3}} A_T^{\frac{1}{3}}}{\left(A_P^{\frac{1}{3}} + A_T^{\frac{1}{3}}\right)}\right] MeV$$

where $I_P = \left(\frac{N_P - Z_P}{A_P}\right)$ & $I_T = \left(\frac{N_T - Z_T}{A_T}\right)$ are the isospin asymmetry of the reacting nuclei. In present approach [5-15], the energy dependent diffuseness parameter $a(E_{c.m.})$ is defined as

$$a(E_{c.m.}) = 0.85\left(1 + \frac{r_0}{13.75\left(A_P^{-\frac{1}{3}} + A_T^{-\frac{1}{3}}\right)\left(1 + \exp\left(\frac{\frac{E_{c.m.}}{V_{B0}} - 0.96}{0.03}\right)\right)}\right) fm$$

Where, $E_{c.m.}$ and V_{B0} respectively are bombarding energy and Coulomb barrier height. The range parameter (r_0) is related with the geometrical structure of the fusing partners via $R_0 = r_0\left(A_P^{1/3} + A_T^{1/3}\right)$. For more details about the model one should check Refs. [5-15].

Result and discussion

For the studied system, the values of Coulomb barrier $V_{B0} = 98.21 MeV$, barrier position $R_B = 10.70\, fm$ and barrier curvature $\hbar\omega = 3.71 MeV$ have been used in the EDWSP calculations. The parameters of the nucleus-nucleus potential are depth $V_0 = 98.07 MeV$, range parameter $r_0 = 1.133\, fm$ and diffuseness (a) varies from $0.97 - 0.85\, fm$ as incident energy varies from $E_{c.m.} = 88 - 110 MeV$. The calculated cross-sections obtained by using abovementioned parameters in the EDWSP model adequately retrieved the order of the experimental cross-sections in sub-barrier domain. Due to energy dependent nature of Woods-Saxon potential, it becomes much more attractive in below barrier realm and estimates substantially larger fusion cross-sections. The same is evident from Fig. 1, where the adopted model predictions are turned out to be much larger than the no-coupling calculations. The no coupling estimations are carried out by using CCFULL code [16].

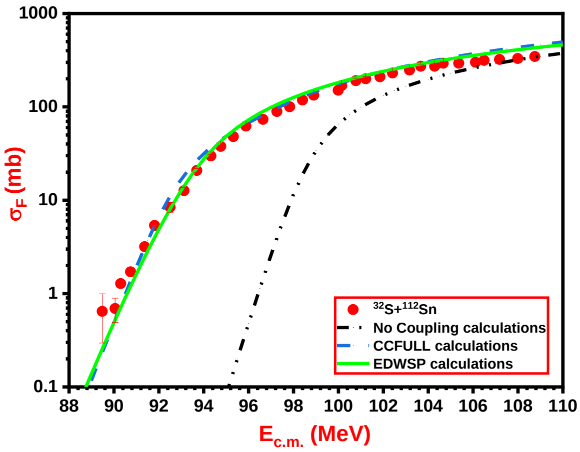

Fig. 1: The fusion cross-sections of ^{32}S + ^{112}Sn reaction estimated by opting the code CCFULL & EDWSP approach along-with with fusion data [17].

The fusing nuclei are spherical and hence their vibrational states are the dominant mode of couplings for present system. The deformation parameters & corresponding excitation energies needed for theoretical estimations are taken from Ref. [17]. The couplings to single phonon 2^+ & 3^- of the both fusing nuclei predict much larger fusion cross-section when compared with no coupling case but unable to reproduce the experimental fusion cross-sections in sub-barrier domain. To improve the theoretical outcomes, the couplings to double-phonon 2^+ in target and single phonon 3^- in target & single phonon 2^+ & 3^- in the projectile along-with their mutual couplings are incorporated in numerical estimations. By considering aforementioned quantum states, the coupled channel calculations are able to describe the reported data reasonably in the entire range of the bombarding energies (see Fig. 1). Tripathi *et al.* [17], suggested that the inelastic surface excitations of type 2^+ & 3^- of the fusing partners are primarily needed for the explanation of the reported data. Without taking into account of the above-mentioned intrinsic channels, the coupled channels predictions cannot describe the reported data of the present system in sub-barrier realm. The couplings to collective surface excitations linked with the fusing partners with their relative motion bring a distribution of barriers. In this barrier distribution, some barriers have their heights smaller with respect to the nominal barrier are reason behind the shifting of the incoming flux from elastic channel to fusion channel and therefore fairly address the experimental data of given reaction. The similar conclusions were also inferred from work of Gautam [18].

Conclusion

This paper analyzed the importance of nuclear structure degree of freedom associated with collision partners as well as energy dependent nature of the nucleus-nucleus potential in the fusion process of ^{32}S + ^{112}Sn reaction in sub-barrier domain. The barrier lowering effects are the fundamental ingredient of the EDWSP approach and as a result of it, there are barrier modification and hence the present method fairly describes the reaction dynamics of the present system. In the similar analogy, the coupling of intrinsic channels of the collision systems with their relative motion produces barrier lowering effects and hence CCFULL predictions appropriately explain the observed dynamics of the given reaction. This suggests that the barrier lowering induces as consequence of the energy dependent nature of the interaction potential simulates the dominant influences of the inherent channels in the reaction dynamics of the present reaction.

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