Fusion dynamics of ${}^{20}_{10}Ne + {}^{208}_{82}Pb$ reaction using static and energy dependent Woods-Saxon potential

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In the past few decades, heavy ion fusion reactions are extensively investigated as the same can be used to probe the role of nuclear structure of fusing nuclei and associated compound nucleus formation dynamics. The simplest theoretical way to understand the fusion process is the barrier penetration model (BPM), wherein the colliding systems penetrate through the interaction barrier to form a composite system [1]. In literature, substantially large enhancement of the fusion excitation function with reference to the expectations of one dimensional barrier penetration model has been reported for various projectile-target combinations. Such sub-barrier fusion enhancement is directly related with the coupling of the relative motion of colliding systems with their nuclear structure degrees of freedom like static deformation, dynamical deformation, low lying vibrations of nuclear surface, neck formation, nucleon transfer reactions etc. Strictly speaking, the coupling between relative motion of collision partners to their intrinsic degrees of freedom leads to an anomalously large enhancement of the fusion excitation functions in the close vicinity of the Coulomb barrier. Although, it is impossible to accommodate all the nuclear structure degrees of freedom simultaneously but one can include the relevant channel in the theoretical calculations which has the strong impact on sub-barrier fusion dynamics.

Furthermore, for complete description of sub-barrier fusion dynamics, the basic knowledge of the nucleus-nucleus potential which consists of Coulomb repulsive interaction, centrifugal term and the attractive short range nuclear potential is essentially required. The dynamics of nuclear reactions like elastic scattering, inelastic scattering, fusion reactions or other reaction channel are quite sensitive to the shape of nucleus-nucleus potential, henceforth different forms of the nuclear potential are used to address various aspects of different nuclear phenomena [1]. The fusion process is generally explored by using the three parametric Woods-Saxon potential wherein depth, range and diffuseness are interrelated with each other. The diffuseness parameter is directly related with the slope of nuclear potential in the tail region of the Coulomb barrier which is in general is taken as onset for occurrence of fusion. It has been well established fact that significantly larger values of diffuseness parameter (0.75*fm* to 1.5*fm*) have been used to probe the sub-barrier fusion data. While much smaller value of diffuseness parameter (0.65*fm*) is best suited for explanation of the elastic scattering data [1]. This diffuseness anomaly is still being work out. Therefore, more intensive investigations on theoretical as well as the experimental front are required to address this issue. In this regard, several attempts have been made to understand the cause of diffuseness anomaly by introducing the energy dependence in the real part of nuclear potential in such a way that it becomes more attractive at sub-barrier energies [2]. The parameters of energy dependent Woods-Saxon potential model (EDWSP model) are defined below

$$a(E) = 0.85\left[1 + \frac{r_0}{13.75\left(A_P^{-\frac{1}{3}} + A_T^{-\frac{1}{3}}\right)\left(1 + \exp\left(\frac{\frac{E}{V_B} - 0.96}{0.03}\right)\right)}\right] fm$$

and

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

where $I_P = \left(\frac{N_P - Z_P}{A_P}\right)$ and $I_T = \left(\frac{N_T - Z_T}{A_T}\right)$

are the isospin asymmetry of the colliding pairs. The energy dependence in the Woods-Saxon potential is incorporated via its diffuseness parameter. Since the channel coupling effects responsible for enhancing sub-barrier fusion cross-section are the surfacial effects which in turn modify the surface diffuseness as well as the surface energy of the collision partners. Therefore it is necessary to reconcile the depth of the potential which includes the surface energy term that plays a very important role in fusion dynamics.

To understand the importance of coupling of inelastic surface excitations of the colliding pairs, the present work is carried out to analyze the fusion dynamics of ${}^{20}_{10}Ne + {}^{208}_{82}Pb$ reaction within the view of static Woods-Saxon potential model and the energy dependent Woods-Saxon potential model in conjunction with one dimensional Wong formula [3]. The ${}^{20}_{10}Ne$ is non-magic nucleus while the ${}^{208}_{82}Pb$ nucleus is doubly magic nucleus and hence the collision partners allow the inelastic surface excitations as dominant mode of coupling. For this system the diffuseness parameter 'a' varies from $a = 0.986\ fm$ to $a = 0.850\ fm$ in the energy range from $E_{c.m.}$ = 80 *MeV* to $E_{c.m.}$ = 108*MeV*. The value of depth parameter (V_0) comes out to be 91.28*MeV* while the range parameter 'r_0' is kept fixed at 1.120 *fm*. The barrier characteristics like V_B, R_B and $\hbar\omega$ are 92.24*MeV*, 11.98*fm* and 4.50 *MeV* respectively.

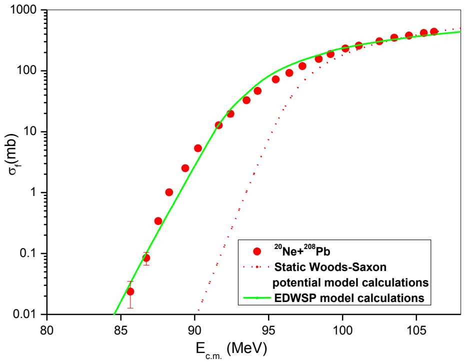

Fig.1. Fusion excitation functions of ${}^{20}_{10}Ne + {}^{208}_{82}Pb$ reaction based upon static Woods-Saxon potential and the EDWSP model along with one dimensional Wong formula [3]. The theoretical predictions are compared with the available experimental data taken from Ref. [4].

In the earlier works, the EDWSP model has been successfully used to probe the fusion dynamics of a wide range of projectile-target combinations [2]. This work explores the comparison of static Woods-Saxon potential and the EDWSP model along with one dimensional Wong formula for description of fusion dynamics of ${}^{20}_{10}Ne + {}^{208}_{82}Pb$ reaction. The theoretical calculations based upon static Woods-Saxon potential are strongly underestimated by the experimental data particularly at below barrier energies while the EDWSP model based calculations provide the complete description of the observed fusion dynamics of ${}^{20}_{10}Ne + {}^{208}_{82}Pb$ reaction. It is relevant to mentioned here that the coupled channel calculations suggest that the coupling to inelastic surface vibrational states of the colliding nuclei are essentially required in order to achieve the complete description of the observed fusion data. Therefore, it is relevant to mentioned here that the energy dependence in Woods-Saxon potential simulates the dominant effects of nuclear structure degrees of freedom of colliding nuclei as evident from Fig.1.

In summary, the present work compares the theoretical predictions based on static Woods-Saxon potential and the EDWSP model along with one dimensional Wong formula. For ${}^{20}_{10}Ne + {}^{208}_{82}Pb$ reaction, the theoretical calculations obtained by using static Woods-Saxon potential are substantially smaller than that of experimental data at below barrier energies and explain the fusion data at above barrier energies only. On the other hand, the EDWSP model based calculations adequately describe the observed fusion enhancement of ${}^{20}_{10}Ne + {}^{208}_{82}Pb$ reaction in whole range of energy spread across the Coulomb barrier. Furthermore, a wide range of the diffuseness parameter ranging from 0.96 *fm* to 0.85 *fm* is required to address the sub-barrier fusion data.

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