# Theoretical approach to explore the fusion dynamics of $^{16}$O + $^{112}$Sn reaction

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## Introduction

The investigation of fusion dynamics using theoretical models is one of the best method for extracting the relevant information regarding the properties of nuclear structure and their participation in the reaction dynamics around the Coulomb barrier. Therefore, the heavy ion fusion reactions are extensively studied during last four decades. In fusion process, the projectile and target are fused together into potential pocket and form single heavy compound nucleus with a release of tremendous amount of energy. The anomalous enhancement of fusion cross-sections data at energies lying below the Coulomb barrier is termed as sub-barrier fusion enhancement and thus such behaviors were observed for variety target-projectile systems [1-2]. The underlying reasons for the anomalous enhancement of fusion cross-sections data in sub-barrier domain were linked with the internal structure degrees of freedom of the collision systems. For signifying the impacts of individual intrinsic channels, the coupled channel approach was turned out to be most appropriate and was extensively used in literature. In coupled channel approach, all such relevant intrinsic channels associated with fusing pairs are coupled to their relative motion. The coupled channel calculations carried out by including the above-mentioned intrinsic channels properly retrieved the experimental data of the fusing partner under study [3-4]. The EDWSP model is one of the theoretical methods, which was used in literature to investigate the fusion process of distinct heavy-ion systems. In this work, the fusion dynamics of $^{16}$O + $^{112}$Sn reaction [5] is theoretically investigated by using standard Woods-Saxon potential and EDWSP model [6-13] within the framework of simple Wong formula [14].

## Theoretical model

In this article, the Woods-Saxon parameterization for the nuclear part of the total nucleus-nucleus potential is used for the theoretical calculations. This form of the nuclear potential depends on three parameters: depth, range and diffuseness. In the EDWSP method, the potential depth is parameterized by the following relation.

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

where $I_T = \left(\frac{N_T - Z_T}{A_T}\right)$ and $I_P = \left(\frac{N_P - Z_P}{A_P}\right)$ are the isospin asymmetry of reacting partners. The diffuseness parameter $a(E_{c.m.})$, in the EDWSP model [6-13], is taken as energy dependent in nature and hence is defined as

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

$E_{c.m.}$ is the bombarding energy in center of mass frame and $V_{B0}$ is the height of Coulomb barrier. The range parameter ($r_0$) is related with the geometry of the fusing partners via $R_0 = r_0\left(A_P^{1/3} + A_T^{1/3}\right)$. The simple Wong formula [14] is defined by the following equation.

$$\sigma_F = \frac{\hbar\omega R_B^2}{2E_{c.m.}} \ln\left[1 + \exp\left(\frac{2\pi}{\hbar\omega}\left(E_{c.m.} - V_{B0}\right)\right)\right]$$

with, $V_{B0}$ is the Coulomb barrier, $R_B$ is the barrier position and $\hbar\omega$ is the barrier curvature.

## Result and discussion

In this section, the results of theoretical approach for the fusion dynamics of $^{16}$O + $^{112}$Sn reaction are presented. The calculational details of studied system are shown in Fig. 1. For given reaction, the Coulomb barrier $V_{B0} = 51.35 MeV$, barrier position $R_B = 10.27\ fm$ and barrier curvature $\hbar\omega = 3.81 MeV$ are used for the theoretical estimations. The parameters of the nuclear potential are $V_0 = 62.11 MeV$, $r_0 = 1.122 fm$ and $a = 0.63 fm$. The Wong based calculations are unable to reproduce the experimental data particularly at sub-barrier domain, which clearly suggested that the intrinsic degrees of freedom are essentially required for adequate description of the fusion dynamics of $^{16}O$ + $^{112}Sn$ reaction. Tripathi *et al.* [5], pointed out that the low-lying vibrational modes like $2^+$ and $3^-$ of the target isotope are primary ingredients in the coupled channel approach and hence are dominant intrinsic channels needed for explanation of the observed sub-barrier fusion enhancement. The similar conclusions are also reflected from our earlier work [15].

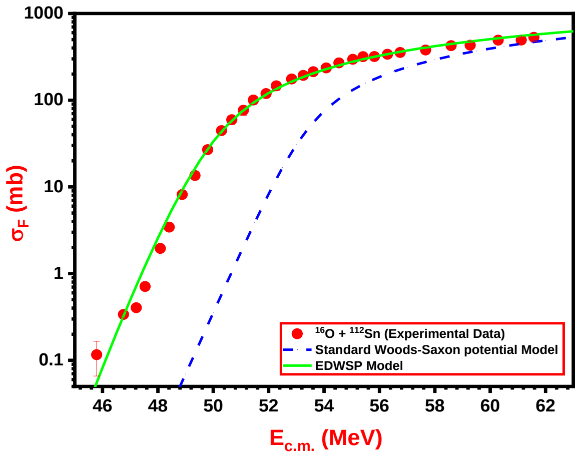


**Fig. 1:** Fusion cross-sections of $^{16}O$ + $^{112}Sn$ reaction obtained by using EDWSP model and one-dimensional Woods-Saxon potential. The predicted results are compared with the reported data [5].

The energy dependent Woods-Saxon potential influences barrier lowering effects and, as a result, affects the interaction barrier properties. The effective fusion barrier between fusing systems gets reduced noticeably and the EDWSP calculations predict larger fusion cross-sections in comparison to that of the Wong formula. In this context, the EDWSP calculations fairly address the reported fusion enhancement of the studied system as reflected from Fig. 1. In the EDWSP model, the parameters of the nuclear potential are depth $V_0 = 62.11 MeV$, range parameter $r_0 = 1.122 fm$ and diffuseness ($a$) varies from $0.96 - 0.85 fm$ as bombarding energy ($E_{c.m.}$) varies from $40 - 65 MeV$. The barrier lowering effects are the basic ingredient of the EDWSP model and hence in the essence of barrier modification effects, the present model appropriately explains the dynamics of the given reaction. The similar kinds of barrier lowering, as reflected in the coupled channel analysis, are producing in the EDWSP calculations. In the EDWSP model, the barrier lowering originates due to energy dependent nature of the interaction potential and thus such energy dependence in the nucleus-nucleus potential mimics the influences of dominant channel couplings in the fusion dynamics of the given reaction.

**Conclusion**

The present work analyzed the fusion dynamics of $^{16}O$ + $^{112}Sn$ reaction around the Colombo barrier. The theoretical calculations are carried out by considering the standard Woods-Saxon potential and EDWSP model in combination with the standard Wong formula. The estimations due simple Woods-Saxon potential are not capable for explaining the observed fusion dynamics of the given reaction in the whole range of incident energies. This suggested that the intrinsic degrees of freedom associated with the target isotope are primarily required for adequate description of the studied system. Without including dominant intrinsic channels, the coupled channel outcomes are not able to explain the observed sub-barrier fusion enhancement of $^{16}O$ + $^{112}Sn$ reaction as pointed out in literature. However, the EDWSP model intrinsically includes the impacts of the collective surface excitations of the reactants and/or other static and dynamic physical effects. As a result of the energy dependency in nuclear potential, the EDWSP model governs barrier lowering and hence fairly retrieves the observed fusion data of the present reaction.

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