Fusion dynamics of ^{32}S + ^{116}Sn reaction

Manjeet Singh Gautam[1*], Manoj Kumar[2], Sonu[2], Hitender Kumar[3], Samiksha[4],
Pushpal Ruhal[4] and Samiksha[5]
[1]*Department of Physics, Government College Alewa, Jind(Haryana)-126102, India,*
[2]*Department of Mathematics, Government College Alewa, Jind(Haryana)-126102, India*
[3]*Department of Physics, Government College for Women,Gharaunda, Karnal(Haryana)-132114, India, and*
[4]*Department of Physics, IHL BPS Mahila Vishwavidyalaya, Khanpur Kalan Sonipat, (Haryana)-131305, India*
[5]*Department of Physics, Chaudhary Ranbir Singh University,, Jind(Haryana)-126102, India,*
[*]Email: gautammanjeetphysics@gmail.com

Fusion process in which two nuclei approaching each other with a sufficient amount of kinetic energy and either by overcoming of the interaction barrier or via quantum mechanical tunneling fused into a potential pocket and form a compound nucleus. In this process large amount of energy is released. This process is a possible path that powers the Sun and other stars in stellar environment. Fusion process also a path that can be utilized as an ultimate future energy source on earth surface. The heavy ion fusion reactions were extensively investigated in last few decades to explore role of nuclear structure properties of fusing partners in reaction dynamics. However, many characteristic features of these reactions are still unexplored and require intensive and extensive investigations on theoretical and experimental fronts [1].

In past, the experimental measurements of various heavy ion fusion reactions were carried out by different authors and measured fusion data was found to be substantially larger than that of the expected from one dimensional barrier penetration model (BPM). The cause of such sub-barrier fusion enhancement over the expectations of one dimensional BPM was linked with the internal structure degrees of freedom of the collision partners. The zero point motion of nuclear surface, low lying collective surface excitations, static deformations and higher order deformations and nucleon transfer channels was identified as dominant factor that are responsible for enhancing fusion cross-sections data at sub-barrier energies [2-3]. Such behavior of fusion cross-sections around the Coulomb barrier was seemed to be general feature of projectile-target system lying in medium and heavy mass regions. The standard way to address the effects of all these nuclear structure degrees of freedom of the collision partners is to use the coupled channel approach [4]. However, it is very difficult to identify the effects of weak channels on fusion process and whenever large number of intrinsic channels are involved in this process, it is not easy to consider the all these channel in coupled channel calculations. In such a situation, an alternative approach is adopted.

In the present work, the fusion dynamics of ^{32}S+^{116}Sn reaction is investigated by opting energy dependent Woods-Saxon potential (EDWSP) model [5-10] and calculations are performed by considering energy dependent Woods-Saxon potential within the Wong formula [11]. In Ref. [12], authors measured the experimental data and theoretically explored the data by using coupled channel approach. The fusion data was found to be significantly enhanced relative to the outputs of the one dimensional BPM especially at below barrier energies. To explain such sub-barrier fusion enhancement, authors consider the low lying vibrational states of like quadrupole (2^+) and octupole (3^-) states of the both collision partners. Using 2^+ and 3^- vibrational states of the collision partners, authors obtain good fit with the experimental data points and also recovers the shape of experimental barrier distribution for studied system. Without considering multiphonon states of type 2^+ and 3^- one is unable to reproduce the experimental data. Further, the two neutron transfer channels for studied reaction have positive Q-value, but this transfer channel has almost negligible effects on fusion process of given reaction.

In the present work, the EDWSP model is utilized to address the fusion anomalies of ^{32}S+^{116}Sn reaction and EDWSP model as a consequence of the energy dependent nature, produces barrier modulation effects. These barrier modulation effects bring lowering of the effective fusion barrier between the participants and predicts larger fusion cross-sections data over the expectations of the one dimensional BPM. In EDWSP model, the conventional form of the Woods-Saxon potential, which is defined below, is opted for the calculations.

$$V_N(r) = \frac{-V_0}{\left[1+\exp\left(\frac{r-R_0}{a}\right)\right]}$$

were, V_0 is depth; R_0 is sum of radii of fusing systems and 'a' is diffuseness of nuclear potential. For $\ell=0$, the contribution of centrifugal potential is zero and sum of nuclear potential and Coulomb potential at barrier position is termed as Coulomb barrier. In EDWSP model; the depth of potential is obtained by considering standard parameterization that depends upon masses and charges of interacting nuclei and is given below.

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

with $I_P = \left(\frac{N_P - Z_P}{A_P}\right)$ & $I_T = \left(\frac{N_T - Z_T}{A_T}\right)$ are the isospin asymmetry of the fusing systems. In EDWSP model [5-10], the energy dependence in the Woods-Saxon is considered by taking energy dependent diffuseness parameter $a(E_{c.m.})$ which is defined below

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

with, $E_{c.m.}$ and V_{B0} respectively are bombarding energy and Coulomb barrier height. The range parameter (r_0) is lined with the geometrical shape of the fusing partners via $R_0 = r_0\left(A_P^{1/3} + A_T^{1/3}\right)$. For more details about the EDWSP model one should go through Refs. [5-10].

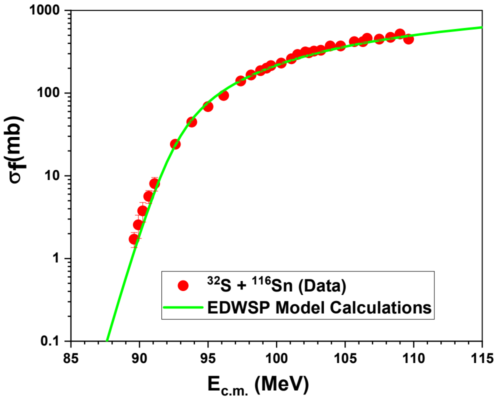

Fig.1 The fusion cross-sections for ^{32}S+^{116}Sn reaction obtained using the EDWSP model and results are compared with the experimental data, which is taken from the Ref. [12].

EDWSP model modulates interaction barrier between the fusing partners and causes splitting of single fusion barrier into a group of energy dependent fusion barrier of different heights and weights. In this spectrum of energy dependent fusion barrier, some of barriers have their heights lower than that of the uncoupled Coulomb barrier. This allows flux lost from the elastic channel to fusion channel and hence EDWSP model is capable of predicting larger fusion cross-sections relative to the outputs of the one dimensional BPM. In EDWSP model, the range parameter (r_0) depends upon the nature of interacting nuclei and geometrical shape of fusing nuclei during fusion process. Therefore, by choosing an appropriate value of range parameter that depends upon projectile-target combination, one can include the effects of dominant channel couplings into EDWSP formalism and EDWSP based calculations. For given reaction $r_0 = 1.135\,fm$, brings sufficient barrier lowering effects, which are quite similar to that appeared in the coupled channel approach.

In summary, the EDWSP based calculations produces similar barrier modifications and barrier lowering as appeared in the coupled channel approach due to couplings of relative motion between the fusing systems to their intrinsic degrees of freedom. Hence, the energy dependency in the EDWSP model empirically considers the effects of all the relevant channel couplings that are originated due to nuclear structure degrees of freedom of the fusing pairs and hence fairly explained the sub-barrier fusion dynamics of ^{32}S+^{116}Sn reaction around the Coulomb barrier.

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