Sub-barrier Fusion of ${}^{40}_{20}Ca + {}^{90}_{40}Zr$ system with modified Woods-Saxon Potential

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In the analysis of any nuclear reaction data the shape of nucleus-nucleus potential, which consists of long range Coulomb repulsive interaction, centrifugal term and the attractive short range nuclear potential, is one of the most important inputs. The Coulomb and centrifugal terms are well understood whereas there are large ambiguities in the nuclear potential which is generally parameterized by Woods-Saxon form. In the Woods-Saxon parameterization of nuclear potential the diffuseness parameter is one of the ingredient parameter which defines the slope of the nuclear potential in the tail region of Coulomb barrier where fusion starts to take place. In the last decade, it was realized that the large values of diffuseness parameter ranging from $a = 0.75\,fm$ to $a = 1.5\,fm$, which are much larger than the expected value $a = 0.65\,fm$ deduced from the elastic scattering data, is required to reproduce the systematics of sub-barrier fusion cross-section [1,2]. The energy dependence of the potential was also recognized in the microscopic double folding model wherein it originates from the energy dependence of underlying nucleon-nucleon interaction and from non-local quantum effects. Thus the energy dependence, which may mocks up some dynamical effects which are important in the analysis of the sub-barrier fusion process, may provide better description of these processes. In Ref.[3] the energy dependence of the nuclear potential is included through the energy dependence of its radius. Here we have taken into account the energy dependence of the potential through the diffuseness parameter and have proposed the following energy dependent parameterization scheme for evaluating the diffuseness parameter

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

We have used this expression of diffuseness parameter [4] and the code CCFULL [5] to calculate the fusion excitation functions for ${}^{40}_{20}Ca + {}^{90}_{40}Zr$ system. This particular system is chosen because both ${}^{40}_{20}Ca$ as well as ${}^{90}_{40}Zr$ nuclei are doubly magic nuclei and it is sufficient to consider only low lying surface vibrational states about their equilibrium shape. Here we have considered only the quadrupole and octapole vibrational states of the projectile and target and the corresponding values of the deformation parameter (β_λ) and the excitation energies (E_λ) needed in the calculation have been taken from Ref.[6]. The depth (V_0) and range (r_0) parameter of the nuclear potential are kept fixed at $V_0 = 100\,MeV$ and $r_0 = 1.1\,fm$ throughout. The Coulomb barrier height for this system is *99.80MeV* [6].

In Fig.1, we compare the fusion excitation function of ${}^{40}_{20}Ca + {}^{90}_{40}Zr$ system obtained by employing our new prescription for potential diffuseness in the code CCFULL and by considering the coupling to low lying vibrational states with the corresponding data. In particular, we have considered three phonon quadrupole and octapole vibration in target and one phonon quadrupole and octapole vibration in projectile. The results are also compared with those obtained by using Aage Winther and Akyüz-Winther parameterization for potential diffuseness. It is clearly observed in this figure that the experimental data is substantially underestimated by the calculation performed by using the Aage Winther [7]and Akyüz-Winther [8]parameterization schemes. The agreement between the data and the present calculations is reasonably good.

Further, we have checked the applicability of this parameterization scheme over wide range of projectile target combinations and have found better agreement between data and prediction in comparison to Aage Winther and Akyüz-Winther parameterization schemes[4].

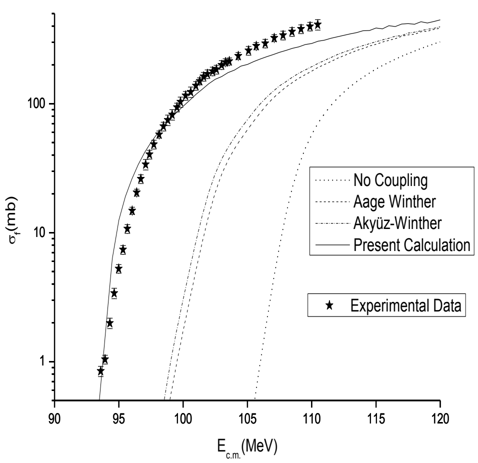

Fig1. Fusion excitation function of ${}^{40}_{20}Ca + {}^{90}_{40}Zr$ system corresponding to various couplings along with experimental data taken from the Ref. [6].

We have concluded that a large value of the diffuseness parameter as compared to value extracted from the elastic scattering data is required in order to fit the sub-barrier fusion data. Further, it has also been found that there occurs a significant enhancement in the sub-barrier fusion cross-sections due to the coupling to low lying surface vibrational states of the projectile and target.

In nutshell, we have proposed a new energy dependent parameterization scheme for determining the diffuseness parameter of Woods-Saxon potential during nucleus- nucleus collision which when used in conjunction with the code CCFULL reproduces the experimental fusion excitation function over a wide range of projectile target combinations very well.

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