Entrance channel mass asymmetry effects in the fusion dynamics of $^{16}O+^{76}Ge$ and $^{18}O+^{74}Ge$ reactions around the Coulomb barrier

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In heavy ion fusion reactions, the experimental fusion cross-section data have been found to be strongly influenced by nuclear structure degrees of freedom like low lying inelastic surface excitation, nuclear deformation, neck formation, zero point motion, entrance channel mass asymmetry effects and particle transfer channels [1]. In literature, it has been pointed out that the entrance channel mass asymmetry of participating nuclei strongly affects the fusion yields at near barrier energy regions [2-3]. Therefore, this paper primarily investigates role of entrance channel mass asymmetry in the fusion dynamics of $^{16}O+^{76}Ge$ and $^{18}O+^{74}Ge$ reactions [4]. The calculations are done by adopting standard Woods-Saxon potential model and the energy dependent Woods-Saxon potential (EDWSP) model [5-7]. The standard Woods-Saxon potential depends upon three variables: range, depth and diffuseness and thus static in nature and is defined as

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

where, V_0 is depth of nuclear potential, r is the range and a is the diffuseness parameter of the nuclear potential. On the other hand, in EDWSP model, the form of nuclear potential is of the Woods-Saxon type but its parameters are defined as

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

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 participating nuclei. In EDWSP model, the energy dependent diffuseness parameter $a(E)$ is defined as

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

$E_{c.m.}$ is the incident energy in center of mass frame, V_{B0} is height of the Coulomb barrier and r_0 is the range parameter that describes the radii of participating nuclei.

In present paper, the standard Woods-Saxon potential model and the EDWSP model are used along with one dimensional Wong formula [8] to estimate the fusion cross-sections of the studied reactions around the Coulomb barrier. The standard Woods-Saxon potential does not involve any energy dependence and as a consequence of its static nature, it gives a single nominal barrier between the participant nuclei. In the absence of barrier lowering effects, the height of the fusion barrier between collision partners is large and subsequently the tunneling phenomenon in sub-barrier energy regimes gets suppressed. As a result, the theoretical calculations strongly under predict the fusion data of $^{16}O+^{76}Ge$ and $^{18}O+^{74}Ge$ reactions as evident from Fig.1.

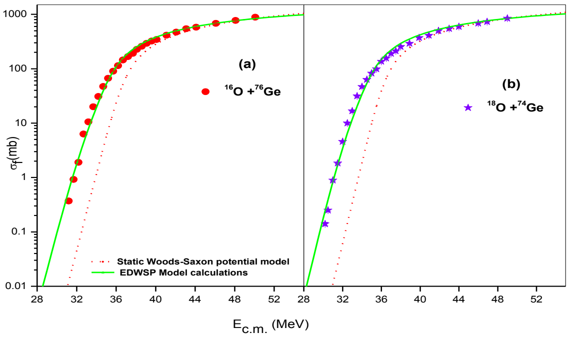

Fig.1. Fusion excitation functions of $^{16}O+^{76}Ge$ (a) and $^{18}O+^{74}Ge$ (b) reaction obtained by using the standard Woods-Saxon potential model and the EDWSP model. The theoretical calculations are compared with the available experimental data taken from Ref. [4].

On the other hand, the energy dependent interaction potential modifies the barrier profile and barrier characteristics of the interaction barrier. As a result, it reduces the effective fusion barrier between colliding nuclei and subsequently EDWSP based calculations predicts larger fusion cross-sections over the outcomes of one dimensional barrier penetration model. In this sense, the EDWSP model reasonably reproduces observed fusion dynamics of studied reactions at near and above barrier energies as depicted in Fig.1.

Furthermore, the effects of the entrance channels mass asymmetry have been investigated for $^{16}O+{}^{76}Ge$ and $^{18}O+{}^{74}Ge$ reactions. Since, chosen reactions results in the formation of a same compound nucleus (^{92}Zr), therefore, it is very interesting to check out the relevance of the entrance channels mass asymmetry effects on the fusion dynamics of studied reactions. The entrance channel mass asymmetry parameter (η) for $^{16}O+{}^{76}Ge$ reaction is $\eta = \left|\frac{A_P - A_T}{A_P + A_T}\right| = 0.65$ and for $^{18}O+{}^{74}Ge$ reaction is $\eta = \left|\frac{A_P - A_T}{A_P + A_T}\right| = 0.60$. In literature, it has been pointed out that the fusion enhancements at sub-barrier energies increases with increase of mass asymmetry in the entrance chancel. The larger mass asymmetric projectile-target combination leads to larger fusion cross-sections at below-barrier energies relative to less mass asymmetric fusing system. In that sense, the fusion cross-sections for $^{16}O+{}^{76}Ge$ reaction are expected to be larger than that for $^{18}O+{}^{74}Ge$ reaction. However, this is not found to be true for the given system as evident from Fig.2. For concrete conclusion, the channel coupling effects are not included in the present calculations and the no-coupling calculations have been done by using the coupled channel code CCFULL [9].

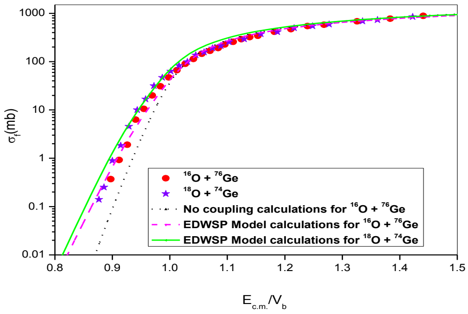

Fig.2. Fusion excitation functions of $^{16}O+{}^{76}Ge$ and $^{18}O+{}^{74}Ge$ systems obtained by using the EDWSP model and coupled channel code CCFULL [9] and results are compared with the experimental data taken from Ref. [4].

As there exist 2n-transfer channel with positive ground state Q-value for $^{18}O+{}^{74}Ge$ reaction and such transfer are expected to enhance magnitude of fusion cross-sections by large amounts relative to $^{16}O+{}^{76}Ge$ reaction. In contrast, the influences of the neutron transfer channels were found to be week. If the impacts of entrance channel mass asymmetry dominate over neutron transfer channel, then the fusion cross-sections of $^{16}O+{}^{76}Ge$ reaction at sub-barrier energies would be larger than that of $^{18}O+{}^{74}Ge$ reaction. But, one can easily notice from Fig.2 that there is sub-barrier fusion enhancement for $^{18}O+{}^{74}Ge$ reaction relative to $^{16}O+{}^{76}Ge$ reaction. Although, the magnitude of sub-barrier fusion enhancements is small but it clearly indicates that effects of neutron transfer channels dominate over the influences of entrance channel mass asymmetry.

In summary, the standard Woods-Saxon potential model and the EDWSP model along with the one dimensional Wong formula are used to investigate the fusion dynamics of $^{16}O+{}^{76}Ge$ and $^{18}O+{}^{74}Ge$ reactions. The calculations based on standard Woods-Saxon potential are unable to recover the observed fusion dynamics of the present reactions. In distinction, as consequence of energy dependence in nucleus-nucleus potential, the EDWSP model leads barrier lowering effects and hence reasonable reproduces the observed fusion dynamics of the studied reactions. Furthermore, the effects of neutron transfer channel are found to be dominating over the influences of entrance channel mass asymmetry. As a result, there is fusion enhancement at sub-barrier energies for $^{18}O+{}^{74}Ge$ relative to $^{16}O+{}^{76}Ge$ reaction. Although, the impacts of entrance channel mass asymmetry in the present case are smaller than that of neutron transfer channel but its effects are non-negligible and hence cannot be ruled out completely. However, to clear these facts more intensive studies are required on this front and may be further investigated in our future work.

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