Effect of nuclear structure in fusion enhancement of ^{19}O+^{12}C reaction at sub-barrier energies

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Introduction

In the recent times, due to availability of radioactive ion beam facilities the use of neutron rich projectiles to probe the fusion dynamics is a topic of immense interest [1]. The investigation of fusion excitation function for isotope series of neutron rich nuclei provides unique prospect. Because, using neutron rich projectiles the Coulomb potential changes a little due to unchanged charge distribution. Therefore, comparative analysis of fusion excitation function for an isotopic chain facilitate to explore the role of attractive nuclear potential with increasing neutron content. Moreover, an enhancement in fusion cross-section is observed using neutron rich nuclei compared to β-stable projectile [2]. It is best studied at near and sub-barrier energies since at low energies the low ℓ-waves are significant, which underpin the role of attractive nuclear potential, are enhanced.

The fusion enhancement has been observed in mass asymmetric reaction ^{15}C+^{232}Th [3]. However, in the light mass region, the study of fusion by employing the exotic projectiles is relevant for astrophysical interest. Because these neutron rich nuclei are estimated as the possible cause of heating of neutron star crust [4]. The experimental study of fusion of $^{18,19}O$ projectiles with ^{12}C target shows fusion enhancement compared to use of stable ^{16}O projectile [5, 6]. Recently, we have investigated the dynamics of compound nuclei (CN) $^{28,30}Si^*$ at same $E_{c.m.}$ = 7.0 MeV. The evaluated fusion cross-sections σ_{fusion}, within DCM, at same $E_{c.m.}$ = 7.0 MeV for CN $^{28}Si^*$ and $^{30}Si^*$, show that LPs are having major contribution in σ_{fusion}. For compound nucleus $^{30}Si^*$, 1n has highest part in σ_{fusion}, which tends to be responsible for observed fusion enhancement in agreement with experimental data [7]. Further, the use of radioactive ^{19}O beam facilitate to study fusion enhancement with exotic projectile. In the present work, dynamics of $^{16,18,19}O$+^{12}C reactions leading to formation of (CN) $^{28,30,31}Si^*$, have been analyzed, comparatively, at sub-barrier energy within dynamical cluster decay model (DCM) [7, 8] approach, to explore the effects of neutron richness of projectile on the reaction mechanism and to look for the underlying cause of fusion enhancement.

Methodology

The DCM is based on quantum mechanical fragmentation theory and is worked out in terms of collective coordinates of mass asymmetry η = (A$_T$-A$_P$)/(A$_T$+A$_P$) and relative separation (R) with effects of temperature, deformation and orientation duly incorporated in it. In terms of these collective coordinates, using the ℓ- partial waves, the decay cross-section is defined as

$$\sigma = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_c}(2\ell+1)P_0P;\ k=\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \quad (1)$$

where ℓ_c, the critical angular momentum, penetrability P refers to R motion and is calculated using WKB approximation, preformation probability P_0 refers to η motion and is given by sol. of stationary Schrodinger

$$\{-\frac{\hbar^2}{2\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}\frac{1}{\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}+V_R(\eta,T)\}\psi^\nu(\eta)$$

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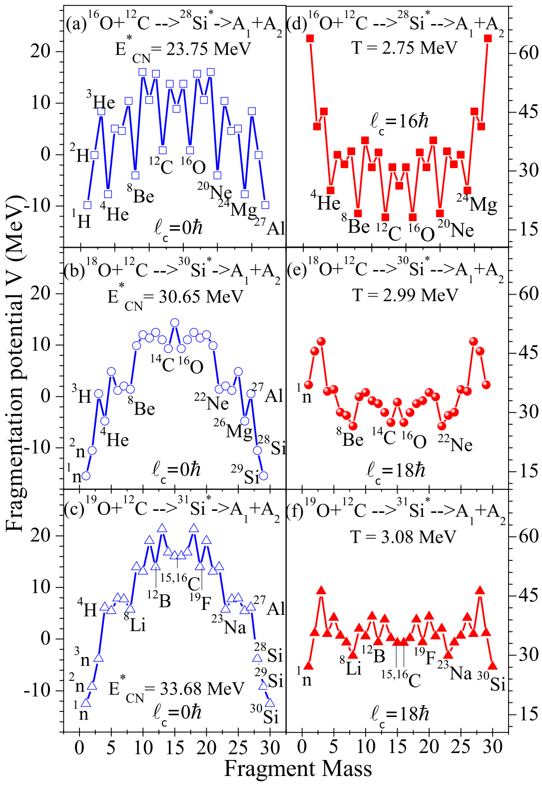

FIG. 1: Fragmentation potential V (MeV) for the decay of (a,d)$^{28}Si^*$ (b,e)$^{30}Si^*$ at $E_{c.m.} = 7.0$ MeV and (c,f)$^{31}Si^*$ at $E_{c.m.} = 7.4$ MeV at $\ell = 0\hbar$ (left panel) and their respective ℓ_c values (right panel).

$$= E^{\nu}\psi^{\nu}(\eta) \quad (2)$$

The minimized fragmentation potential ($V_R(\eta$,T) in eq.2) is the sum of temperature dependent Coulomb, proximity, centrifugal potential along with temperature dependent liquid drop energies and shell effects. For a fixed β_{λ_i}, the potential values for all possible mass (A) combinations corresponding to a given charge (Z) is minimized in mass coordinate (η) and gives the most probable/minimized potential.

Calculations and Discussion

Fig. 1 presents the collective potential energy surface in fragmentation of CN $^{28,30,31}Si^*$ at, $\ell = 0\ \hbar$ (left panel) and the respective critical angular momentum values, ℓ_c (right panel). It is clear from Fig. 1(a,b,c) that light particles (LPs) are minimized at lower ℓ-value. However, at higher ℓ values i.e. at ℓ_c, the characteristic of LPs emission shows drastic change with increasing N/Z ratio of compound nuclei. In the decay of $^{28}Si^*$ compound nucleus, ^8Be, ^{12}C, ^{16}O, ^{20}Ne (nα-clusters) are energetically favorable (Fig. 1(d)), similar to what is encapsulated in Ikeda diagram at threshold decay energy of $E^* = 23.9$ MeV [9]. While for compound nucleus $^{30}Si^*$ in addition to nα-clusters, ^{14}C, ^{22}Ne (xn-xα clusters; x is an integer) are also preferentially minimized (Fig.1(e)). On the other hand, it is interesting to note that in case of compound nucleus $^{31}Si^*$, the LPs are neutron rich which are in strong competition with neighboring xn-xα clusters at ℓ_c value (Fig.1(f)). It will be interesting to look for the role of nuclear structure via preformation probability P_0 of different clusters in these reactions, which plays an imperative role in calculation of fusion cross-sections. Furthermore, the calculations of σ_{fusion} for compound nucleus $^{31}Si^*$ at different excitation energies are in progress, to further investigate the phenomenon of fusion enhancement.

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