Entrance channel effect in the formation of ^{200}Pb*

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Introduction

Study of entrance channel effect on fusion dynamics is of great interest. Fusion is the process in which two nuclei combine to form a compound system which subsequently decay through different modes such as evaporation residue (ER), fusion-fission (ff) and intermediate mass fragments (IMF)etc. Depending on the beam energy and entrance channel mass asymmetry, several other non-Compound nucleus(nCN) process like Deep-Inelastic Collision(DIC), quasi-fission(qf) etc., start competing in addition to fully equilibrated compound nucleus(CN) state. For fusion-process, the incoming projectile must have sufficient energy to cross the Coulomb barrier. During fusion the barrier is formed due to different interaction potentials like long-range Coulomb potential, short range nuclear potential and angular momentum dependent potential etc.

Recently an experiment [1] was performed at eight center-of-mass energies ($E_{c.m.}$) ranging from 107.40 MeV to 136.96 MeV in order to measure the ER cross section and fusion cross section of spherical compound nucleus ^{200}Pb* having magic Z, formed by striking ^{30}Si projectile on ^{170}Er target. Earlier same CN was formed using ^{16}O+^{184}W and ^{19}F+^{181}Ta [2, 3] with $E_{c.m.}$ ranging from 77.19 MeV to 110.56 MeV. In this work we intend to analyze the entrance channel effects in the fusion of ^{200}Pb* using three different reactions via Wong [4] as well as with ℓ-summed Wong formula [5]. It is observed that Wong formula overestimates the data for ^{19}F+^{181}Ta and ^{30}Si+^{170}Er reactions, whereas underestimates the data at few energies for ^{16}O+^{184}W. However with the use of ℓ-summed Wong formula, the cross-sections are fitted nicely for ^{30}Si and ^{19}F-induced reactions. It might be possible that there is some non-compound nucleus contribution at few energies for ^{16}O+^{184}W.

Methodology

According to Wong [4], the fusion cross section, in terms of angular-momentum ℓ partial waves, for deformed and oriented nuclei (with orientation angles θ_i), lying in same planes, and colliding with center-of-mass energy $E_{c.m.}$, is

$$\sigma(E_{c.m.},\theta_i) = \sum_{\ell=0}^{\ell_{max}} \sigma_\ell = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_\ell(E_{c.m.},\theta_i) \quad (1)$$

with k=$\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}}$ and μ is the reduced mass, P_ℓ is the transmission coefficient calculated by using Hill wheeler approximation [6], for each ℓ which describe the penetrability of barrier V_T(R,$E_{c.m.}$,θ_i), given by

$$V_T^\ell(R) = V_C(R,Z_i,\beta_{\lambda i},\theta_i,T)+V_N(R,A_i,\beta_{\lambda i},\theta_i,T) + V_\ell(R,A_i,\beta_{\lambda i},\theta_i,T) \quad (2)$$

Noting that the ℓ-summed expression (1) uses the ℓ-dependent potentials, Gupta and collaborators [5] carried out its ℓ-summation for the ℓ_{max} determined empirically for a best fit to measured cross-section, and the angles θ_i integrated to give fusion cross-section in the framework of ℓ-summed Wong formula as,

$$\sigma(E_{c.m.}) = \int_{\theta_i=0}^{\pi/2}\sigma(E_{c.m.},\theta_i)sin\theta_i d\theta_i. \quad (3)$$

Instead of solving Eq. (1) explicitly, which require the complete ℓ-dependent potentials $V_T^\ell(R)$, Wong [4] applied few approximations to give the ℓ=0 barrier-based Wong formula,

$$\sigma(E_{c.m.},\theta_i) = \frac{R_B^{02}\hbar\omega_0}{2E_{c.m.}}\ln\{1+\exp[\frac{2\pi}{\hbar\omega_0}(E_{c.m.}-V_B^0)]\}, \quad (4)$$

Which on integration over the orientation angle, gives the fusion cross-section as in Eq. (3).

Calculations and Results

In order to study the entrance channel effects, calculations have been done for three

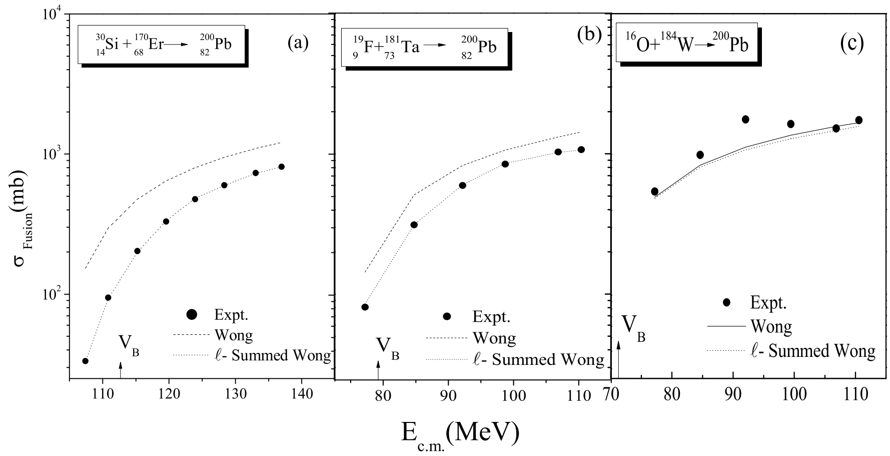

FIG. 1: Comparison of experimental data is made with the calculated fusion cross-section using Wong formula and its extended version, ℓ-summed extended Wong model for (a) ^{30}Si+^{170}Er (b) ^{19}F+^{181}Ta (c) ^{16}O+^{184}W reactions, using quadurpole (β_2) deformation effects.

different channels ^{30}Si+^{170}Er, ^{19}F+^{181}Ta and ^{16}O+^{184}W forming same compound nuclear system ^{200}Pb*. Fig. 1 shows the variation of fusion excitation function with center-of-mass energy ($E_{c.m.}$) for quadurpole (β_2) deformed choice of colliding nuclei. From Fig. 1(a) and Fig. 1(b), it is clear that Wong formula overestimates the experimental data, but ℓ-summed Wong formula fits of fusion cross-sections of ^{30}Si and ^{19}F induced reactions nicely at near as well as above barrier energies.

However, ^{16}O+^{184}W reaction seems to behave different in the sense that neither Wong nor ℓ-summed Wong formula fits the data completely at two-three energy points as shown in Fig. 1(c). The reason behind this discrepancy might be due to higher asymmetry of O-induced reaction. The value of asymmetry parameter (η) is 0.7 for ^{30}Si+^{170}Er, 0.81 for ^{19}F+^{181}Ta and 0.84 for ^{16}O+^{184}W. As the nucleus-nucleus interaction potential for more asymmetric system is more wider and deeper. Therefore, the measured fusion cross-sections for the ^{16}O+^{184}W reaction are larger than those for the ^{19}F and ^{30}Si induced reactions. The dominance of fusion cross-section for ^{16}O-channel may be due to the fact that ^{16}O i.e. projectile and the CN formed i.e. ^{200}Pb* are magic nuclei. Also, the under estimation of data by Wong and ℓ-summed Wong formula seems to suggest that some nCN component is competing with CN process in case of ^{16}O+^{184}W reaction. Though all three entrance channels are populating same CN but choice of different target-projectile combinations is affecting the fusion cross-sections. These facts directly indicates the signature of entrance channel dependence in formation of compound nucleus ^{200}Pb*. It will be of further interest to investigate this entrance channel dependence in decay of ^{200}Pb* by exploiting various decay modes such as ER, ff and IMF etc.

References

[1] G. Mohanto *et al.*, Nucl. Phys. A **890-891**, 62-76 (2012).

[2] D. J. Hinde *et al.*, Nucl. Phys. A **385**, 109 (1982).

[3] P. D. Shidling *et al.*, Phys. Rev C **74**, 064603 (2006).

[4] C. Y. Wong, Phys. Rev. Lett. **31**, 766 (1973).

[5] R. Kumar *et al.*, Phys. Prv. C **80**, 034618 (2009).

[6] D. L. Hill and J. A. Wheeler, Phys. Rev. **89**, 1102 (1953); T. D. Thomas, *ibid.* **116**, 703 (1959).