Dynamics of ^{6}Li+^{197}Au reaction across the Coulomb barrier

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Introduction

Heavy ion fusion reactions are strongly affected by the nuclear structure effects, which not only includes the deformation and relative orientation of the participants but also their corresponding shell closure effects, specially at sub-barrier region. According to Strutinsky [1], the microscopic shell-correction should be combined with the macroscopic contribution for the accurate evaluation of the nuclear binding strength. The shell corrections play an important role in determining or empirical fitting of nuclear masses, because the nuclear masses calculated by using the smooth liquid drop formula show large deviations with respect to the experimental masses. Therefore the entire nucleus-nucleus potential must comprise of the macroscopic interaction and the microscopic contributions. Shell corrections can influence the dynamics of fragments involved and hence it motivates one to check its effect on the fusion cross sections.
The present calculations are performed with reference to the recent available experimental data [2] for the reaction ^{6}Li+^{197}Au$\rightarrow$^{203}Pb*. In this experiment, the fusion cross sections (by summing the cross sections of evaporation residue (ER) channels) were measured for ^{6}Li+^{197}Au at center of mass energies, $E_{c.m.}$=23.5-40 MeV. In view of this, the decay of ^{203}Pb* nucleus has been studied in context of shell corrections using the dynamical cluster-decay model (DCM) [3].

Methodology

The dynamical cluster-decay model (DCM) [3] is based on the collective coordinates of mass (and charge) asymmetry and relative separation R. In terms of ℓ partial waves, the compound nucleus decay cross-section is

$$\sigma = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_0 P \ ; \ k=\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \qquad (1)$$

Here, P_0 is the preformation probability, which can be obtained by solving the stationary Schrödinger equation in η-coordinate, and P the penetrability calculated in WKB approximation. Also, μ is the reduced mass and ℓ_{max} is the maximum angular momentum which is fixed for the vanishing of the ER cross-section. The fragmentation potential $V_R(\eta,T)$ used as input contains the T-dependent binding energies, shell corrections, Coulomb (V_C), nuclear proximity (V_P) and angular momentum (V_ℓ) dependent potentials for deformed, oriented nuclei and is defined as:

$$V(R,\eta,T)=\sum_{i=1}^{2}[V_{LDM}(A_i,Z_i,T)]$$
$$+\sum_{i=1}^{2}[\delta U_i]\exp(-T^2/T_0^2)+V_C(R,Z_i,\beta_{\lambda i},\theta_i,T)$$
$$+V_P(R,A_i,\beta_{\lambda i},\theta_i,T)+V_\ell(R,A_i,\beta_{\lambda i},\theta_i,T) \qquad (2)$$

The shell effects δU, added to the liquid drop energy in the above equation, are obtained empirically by Myers and Swiatecki [4] as

$$\delta U = C\left[\frac{F(N)+F(Z)}{\left(\frac{A}{2}\right)^{\frac{2}{3}}}-cA^{\frac{1}{3}}\right] \qquad (3)$$

with

$$F(X)=\frac{3}{5}\left(\frac{M_i^{\frac{5}{3}}-M_{i-1}^{\frac{5}{3}}}{M_i-M_{i-1}}\right)(X-M_{i-1})$$
$$-\frac{3}{5}\left(X^{\frac{5}{3}}-M_{i-1}^{\frac{5}{3}}\right) \qquad (4)$$

where X = N or Z, M_{i-1} < X < M_i. M_i are the magic numbers 2, 8, 14 (or 20), 28, 50, 82, 126 and 184 for both neutrons and protons. The values of constants 'C' and 'c' are taken as 5.8 MeV and 0.26 MeV respectively.

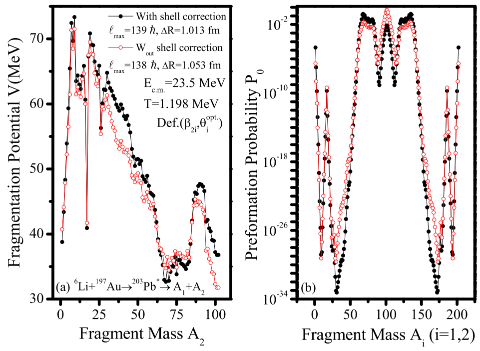

FIG. 1: Effect of shell correction on the (a) fragmentation potential and (b) preformation probability for the reaction ^{6}Li+^{197}Au.

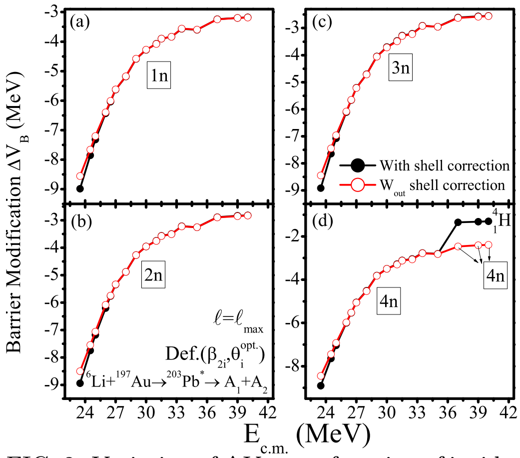

FIG. 2: Variation of ΔV_B as a function of incident energy for ^{203}Pb* calculated using WSC and W_{out} SC for A_2: (a) 1, (b) 2, (c) 3 and (d) 4.

Results and Discussions

Corresponding to the available experimental data [2], the fusion cross sections for the system ^{203}Pb* have been fitted within the framework of DCM using the neck length ΔR for two cases (i) with shell correction (WSC) and (ii) without shell correction (W_{out} SC). In Fig.1 role of shell correction is analyzed on the (a) fragmentation potential and (b) preformation probability at an incident energy $E_{c.m.}$=23.5 MeV below the Coulomb barrier (V_C=29.111 MeV). The contribution of shell correction term is clearly visible on the fragmentation potential. However the shell closure effect looks relatively suppressed in case of preformation factor. The preformation probability shows a double-humped structure in fission region exhibiting asymmetric mass distribution for both the cases.

The fusion cross sections calculated for the nucleus ^{203}Pb* for two cases (WSC and W_{out} SC) are found in nice agreement with the experimental data at all the incident energies (not shown here). For this the neck length required in the case of shell correction is lesser as compared to without shell correction. The choice of neck length for the best fit to the data allows us to define the "barrier modification" ΔV_B which is difference between the actual used barrier $V(R_a,\ell)$, and the calculated barrier $V_B(\ell)$, i.e. $\Delta V_B(\ell)=V(R_a,\ell)-V_B(\ell)$. Effect of shell correction on the barrier modification is shown in Fig.2 at various incident energies for the constituents of evaporation residue. It is evident from the figure that at the lower incident energies, more barrier modification is required when the shell correction term is included in the calculations. As the incident energy approach towards and above the Coulomb barrier, barrier modification requirement is similar for WSC and W_{out} SC. Also, this behaviour is found to be consistent for all the constituents of evaporation residue except for A_2 = 4 at incident energies $E_{c.m.}$=37, 39 and 40 MeV which is due to the change in fragment charge from 0 (in case of W_{out} SC) to 1 (in case of WSC). We also aim to extend this work for other target-projectile combinations for better understanding of nuclear reaction dynamics.

Acknowledgement

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