Role of different microscopic/ macroscopic potentials in the exotic cluster-decay of $^{56}Ni^*$

Narinder K. Dhiman*
Govt. Sr. Sec. School, Summer Hill, Shimla -171005, H.P., INDIA

* *email: narinder.dhiman@gmail.com*

Introduction

Recently, a renewed interest has emerged in nuclear physics research. This includes low energy fusion process, intermediate energy phenomena as well as cluster-decay and/or formation of super heavy nuclei [1]. In the last one decade, several theoretical models have been employed in the literature to estimate the half-lives of various exotic cluster decays of radioactive nuclei. These outcomes have also been compared with experimental data.

Most of the models applied to study exotic cluster decay can be classified into two categories [1]. In the first category, only barrier penetration probabilities are considered. Such models have been labeled as unified fission models. In the second category, clusters are assumed to be formed well before penetration of the barrier. In either of these approaches, one needs complete knowledge of the potential [1]. Our aim is to study the effect of various microscopic/ macroscopic potentials on the cluster decay half-lives.

The scattering potential $V(R)$ consists of repulsive Coulomb part ($Z_1.Z_2\ e^2/R$) and attractive nuclear part $V_N(R)$ of the interaction potential. As we know, Coulomb part of the potential is well-known, in contrast to the nuclear part, which is less defined. Several different approaches exist in literature to derive the nuclear part of the potential [1]. A realistic estimate of the radial dependence of $V_N(R)$ to rather smaller distances is extremely important for the understanding of heavy-ion reaction processes that occur with impact parameter smaller than the grazing impact parameter. The uncertainty of the interaction potential between heavy-ions near the touching configuration gives rise to a variety of proposed nuclear reaction mechanisms. Although most of these potentials are similar at the surface region (see Fig. 1), but have quite different shapes in the interior part of the potential.

For cluster decay calculations, we use the Preformed Cluster Model (PCM) based on well-known quantum mechanical fragmentation theory and its simplification to Unified Fission Model (UFM) [1]. The decay constant λ or decay half-life $T_{1/2}$, is defined as:

$$\lambda = \frac{\ln 2}{T_{1/2}} = \nu_0 P_0 P,$$

where P_0, P and ν_0 refers to the preformation probability, the penetrability and the assault frequency, respectively.

For decoupled Hamiltonian, the Schrödinger equation in η-co-ordinates can be written as:

$$\left\{ -\frac{\hbar^2}{2\sqrt{B_{\eta\eta}}} \frac{\partial}{\partial \eta} \frac{1}{\sqrt{B_{\eta\eta}}} \frac{\partial}{\partial \eta} + V_R(\eta) \right\} \psi(\eta) = E\psi(\eta).$$

Results and Discussions

In order to investigate the cluster decay process, one must know the shape and strength of nuclear potential at smaller distances. The nuclear potentials such as Skyrme Energy Density Model (SEDM) potential, the proximity potentials and other parameterized potentials due to Bass, Christensen-Winther, Ngô-Ngô and Denisov were employed to study the isotopic dependence of fusion probabilities using Ca-Ni colliding series [2]. In the present paper, we plan to investigate the role of these microscopic/ macroscopic theoretical approaches in the cluster decay process. The cluster decay process is studied within PCM and its simplification to UFM. We choose $^{56}Ni^*$ compound system to calculate the decay half-lives with different values of Q_{eff} for different clusters (i.e. variable Q_{eff}).

In Fig. 1, we display the scattering potential $V(R)$ and its nuclear part $V_N(R)$ calculated for the decay of $^{56}Ni^*$ into $^{28}Si+^{28}Si$ fragments using different theoretical approaches. From figure one observes that the nuclear part seems to be similar at the surface but have quite different shape in the interior region.

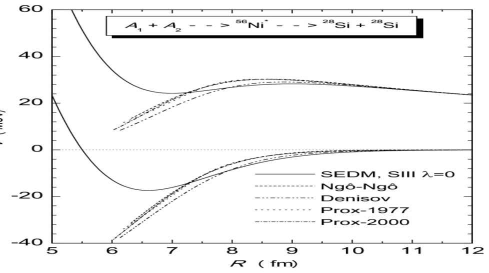

Fig. 1 The scattering potential $V(R)$ (MeV) as a function of inter nuclear distance R (fm) for cluster decay of $^{56}Ni^*$ into $^{28}Si+^{28}Si$ channel.

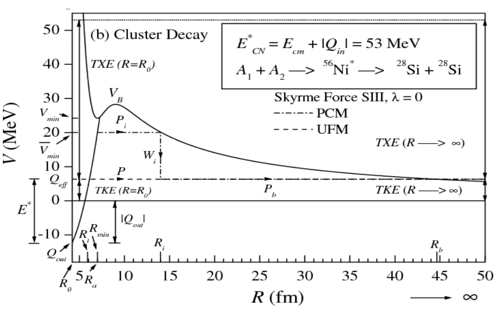

Fig. 2 The scattering potential $V(R)$ (MeV) for cluster decay of $^{56}Ni^*$ into $^{28}Si+^{28}Si$ channel. The distribution of compound nucleus excitation energy E^*_{CN} at both the initial ($R=R_0$) and asymptotic ($R\rightarrow\infty$) stages and total kinetic energy (*TKE*) of the two outgoing fragments and *Q*-values are shown. For cluster decay process, decay paths for both PCM and UFM are shown.

Fig. 2 shows the characteristic scattering potential for cluster decay of $^{56}Ni^*$ into $^{28}Si+^{28}Si$ channel. In the exit channel for compound nucleus to fission, the compound nucleus excitation energy E^*_{CN} goes in compensating the negative Q_{out}, the total excitation energy *TXE* and total kinetic energy *TKE* of the two outgoing fragments as displayed in Fig. 2. For the cluster decay process, the *TKE* plays the role of an effective (positive) *Q*-value (i.e. $TKE=Q_{eff}$) and the decay products (fragments) are excited with total excitation energy *TXE* as displayed.

The fragmentation potentials $V(\eta)$ and fractional yields P_0 for $^{56}Ni^*$ are calculated within PCM at $T=3.0$ MeV using different microscopic/ macroscopic potentials are displayed in Fig. 3(a) and (b), respectively. For the SEDM potential, the fractional yield calculations are made at $R=R_{min}$ with $V(R_{min})=\bar{V}_{min}$, whereas for other theoretical models, it is taken at the touching configuration. The α-nucleus structure of $^{56}Ni^*$, which has its origin in the macroscopic energy of the liquid drop model, is explained by all the theoretical approaches. The calculated fractional yields go into the calculations of cluster decay half-lives in the PCM.

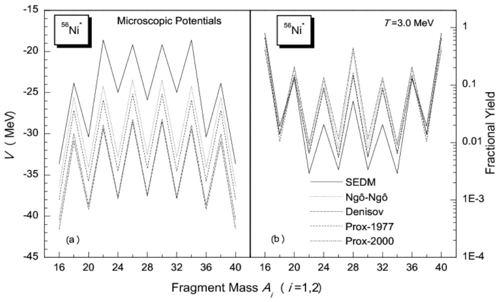

Fig. 3 (a) The fragmentation potential $V(\eta)$ and (b) calculated fission mass distribution yield P_0 for different microscopic/macroscopic potentials.

The results for cluster decay half-lives in $^{56}Ni^*$ are quantified by the following quantity as:

$$[\log T_{1/2}]\% = \frac{(\log T_{1/2})^i - (\log T_{1/2})^{SEDM}}{(\log T_{1/2})^{SEDM}} \times 100,$$

where i stands for different theoretical models. Here, we use Skyrme force SIII with λ=0 in SEDM potential. The variation in the cluster decay half-lives for different clusters lies within ±10% for both PCM and UFM except for few cases.

References

[1] N.K. Dhiman, submitted to Ukr. J. Phys. 2011; N.K. Dhiman, Ph.D. Thesis, Panjab University Chandigarh (2008) and references therein.

[2] N.K. Dhiman and R.K. Puri, Acta Phys. Pol. **B 37**, 1855 (2006) and references therein.