

Cluster-decay of $^{56}\text{Ni}^*$ compound system using different Fermi density parameters

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Introduction

Heavy-ion collisions provide a very good tool to probe the nucleus at low and intermediate energies. This includes low energy fusion, fission, cluster decay processes, intermediate energy multifragmentation, collective flow, particle production as well as formation of super-heavy nuclei [1]. Several theoretical models have been employed in the literature to estimate the half-lives of various exotic cluster decays of different radioactive nuclei. Among all the models employed, Preformed Cluster Model (PCM) is widely used to study the exotic cluster decay process. In this model, the clusters are assumed to be preformed well before the penetration of the barrier. This is in contrast to the unified fission model (UFM), where only barrier penetration probabilities are considered. In all these approaches, one needs the knowledge of nuclear potential as well as nuclear densities.

The experimental data at low relative momentum can be described accurately with two-parameter Fermi density. Among all the density distributions, two-parameters Fermi density has been quite successful in the low, medium and heavy mass regions. A model that uses such type of density distribution has to rely on the information about half density radii (R_0), central density (ρ_0) and surface diffuseness (a). Interestingly, several different experimental as well as theoretical values of these parameters are available in literature [2]. Our aim here is to study the effect of these parameters in the cluster decay of $^{56}\text{Ni}^*$.

To study the effect of Fermi density param-

eters on the cluster decay half-lives, we choose different Fermi density parameters proposed by various authors [2]. These different density parameters are labeled as DV, Ngo, SM, EW and HS, respectively.

For the cluster decay calculations, we use the PCM based on the well known quantum mechanical fragmentation theory [1, 3] and its simplification to UFM. The decay constant λ or decay half-life $T_{1/2}$, is defined as:

$$\lambda = \ln 2/T_{1/2} = P_0\nu_0P, \quad (1)$$

where the preformation probability P_0 refers to the η -motion and the penetrability P to R -motion. The ν_0 is the assault frequency. For decoupled hamiltonian the Schrödinger equation in η -co-ordinates can be written as:

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

Results and Discussion

We present here the cluster decay calculations of ^{56}Ni , when formed in heavy-ion collisions. Since ^{56}Ni is a negative Q -value system and is usually stable against both fission and cluster decay, but when produced in heavy-ion collisions as an excited compound nucleus, depending on the incident energy and angular momentum involved, it could either fission or decay via cluster emission or results in resonance phenomena. The negative Q_{out} having different values for various exit channels. The ^{56}Ni when produced with sufficient compound nucleus excitation energy E_{CN}^* ($= E_{cm} + Q_{in}$), decays to compensate the negative Q_{out} , their total kinetic energy (TKE), the total excitation energy (TXE) and the deformation energy of the fragments (E_d) in the exit channel as: $E_{CN}^* = |Q_{out}| + TKE + TXE + E_d$,

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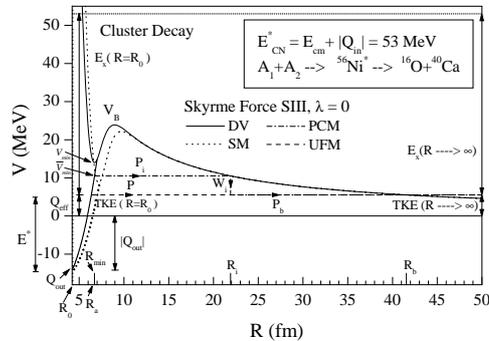


FIG. 1: The scattering potential $V(R)$ (in MeV) for cluster decay of $^{56}\text{Ni}^*$ into $^{28}\text{Si} + ^{28}\text{Si}$ channel for different nuclear radii. The decay path for PCM and UFM is also displayed.

(see Fig. 1, where fragments are considered to be spherical). Here Q_{in} adds to the entrance channel kinetic energy E_{cm} of the incoming nuclei in their ground states.

In Fig. 1, we display the characteristic scattering potential for the cluster decay of $^{56}\text{Ni}^*$ into $^{16}\text{O} + ^{40}\text{Ca}$ channel using DV and SM density parameters, as an illustrative example. In the exit channel, for the compound nucleus to decay, the compound nucleus excitation energy E_{CN}^* goes in compensating the negative Q_{out} , TXE and TKE of the two outgoing fragments. The TKE plays the role of an effective Q -value (Q_{eff}) in the cluster decay process. In addition, we plot the penetration paths for PCM and UFM using Skyrme force SIII (without surface correction factor, $\lambda = 0$) with DV Fermi density parameters. For PCM, we begin the penetration path at $R_a = R_{min}$ with potential at this R_a -value as $V(R_a = R_{min}) = \bar{V}_{min}$ and ends at $R = R_b$, corresponding to $V(R = R_b) = Q_{eff}$, whereas for UFM, we begin at R_a and end at R_b both corresponding to $V(R_a) = V(R_b) = Q_{eff}$. We have chosen the variable Q_{eff} for different fragments to satisfy the arbitrarily relation $Q_{eff} = 0.4(28 - |Q_{out}|)$ MeV [1].

Fig. 2(a) and (b) shows the fragmentation potential $V(\eta)$ and fractional mass distribution yield P_0 at $R = R_{min}$ with $V(R_{min}) = \bar{V}_{min}$. These yields are calculated at $T = 3.0$

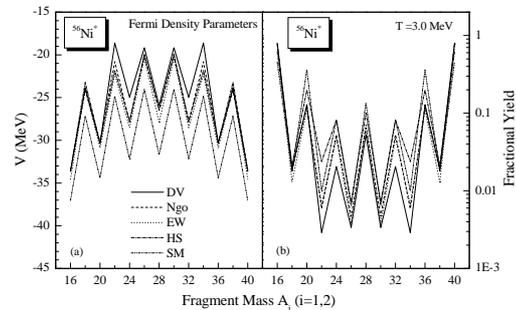


FIG. 2: (a) The fragmentation potential $V(\eta)$ and (b) calculated fractional mass distribution yield with different nuclear radii at $T = 3.0$ MeV.

MeV within PCM using various Fermi density parameters for $^{56}\text{Ni}^*$. From the figure, we observe that different parameters have minimal role in the fractional mass distribution yield. The fine structure is not at all disturbed for different sets of Fermi density parameters.

We have also calculated the half-lives (or decay constants) for $^{56}\text{Ni}^*$ within PCM and UFM for clusters $\geq ^{16}\text{O}$. For PCM, the order of magnitude of cluster decay constants for different density parameters is nearly same, except for SM parameters. Similar trends are observed for UFM. The percentage variation in the half-lives for the PCM lies within $\pm 5\%$ excluding SM parameters, whereas including SM parameters it lies within $\pm 13\%$. In the case of UFM, half-lives lie within $\pm 1.5\%$ for all density parameters except of SM. For SM parameters these variations lie within $\pm 9\%$.

References

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