Cluster pre-existence probability from WKB integral

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Introduction

Spontaneous decay of radioactive nuclei via emission of clusters heavier than α particle is a well established phenomenon in transactinide region. Such cluster emission from the excited light and medium mass parent nuclei formed in low energy reactions are also of much interest recently. Cluster emission could be considered either as a case of asymmetric fission process or as a process of cluster formation and its subsequent emission from the parent nucleus. In models based on the former case the pre-existence probability of the emitted cluster is considered to be equal to one. In the other type of models a finite value of pre-existence probability is considered and which is different for different clusters and is calculated based on only two models.

In one of the models due to Blendowske *et al* [1] the pre-existence probability is considered to be proportional to the squared product of the overlaps between the nucleon states in the emitted fragment (the daughter nucleus) and the states in the ground state wave function of the parent nucleus. The limitation of this model is that it is difficult to calculate pre-existence probability beyond ^{16}O cluster. In the other model due to Malik and Gupta [2], it is possible to calculate the preformation probability of the entire binary mass spectrum of a given nucleus. In this model the preformation probability is considered as a quantum mechanical probability of finding the fragments A_1 and A_2 (with fixed charges Z_1 and Z_2, respectively) and is calculated by solving a stationary Schrödinger equation in the charge minimized mass asymmetry coordinate η at relative separation R. Apart from these models, the preformation probability can be estimated empirically in a model dependent way with respect to the measured half life values.

Poenaru *et al* [3] has proposed that within fission model approach, the preformation probability can be considered as the probability of crossing the pre-scission part of the WKB action integral and estimated the preformation probability values of some clusters. In this work taking the idea of Poenaru *et al* we have estimated the preformation probability for the entire mass spectrum of ^{56}Ni and the results obtained are discussed and compared with the values of preformed cluster model (PCM) of Gupta and collaborators.

Model

In PCM the potential energy of the overlapping region is a second order polynomial of the form,

$$V(R) = a_1 R + a_2 R^2 \quad (1)$$

with R, the distance between the centers of the two emitted nuclei, and for the post scission region, the potential is the sum of Coulomb potential and proximity potential.

$$V(R) = \frac{Z_1 Z_2 e^2}{R} + 4\pi\gamma b\bar{R}\phi(\xi) \quad (2)$$

The decay constant in general is defined as

$$\lambda = P P_0 \nu_0 \quad (3)$$

Here ν_0 is the impinging frequency, P is the barrier penetration probability,

$$P = P_{tot} = \exp[-\frac{2}{\hbar}\int_{R_0}^{R_b} \sqrt{\{2\mu[V(R) - Q]\}}dR] \quad (4)$$

and P_0 is the preformation probability and is 1 in fission approach and takes different values

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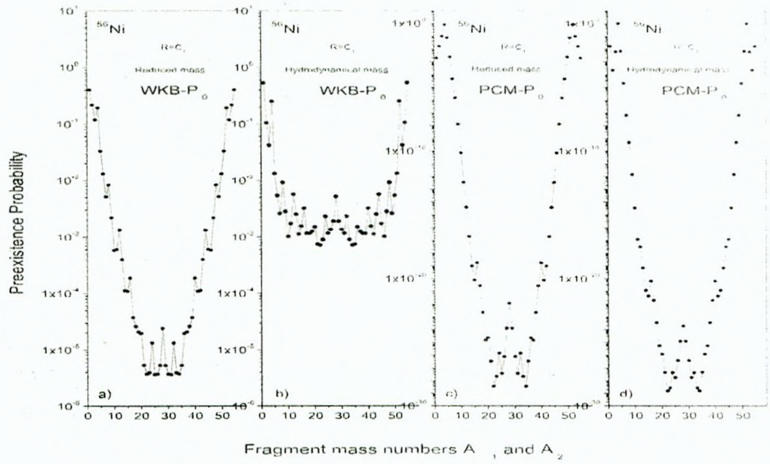

FIG. 1: Pre-existence probability calculated from WKB integral and from PCM for the use of reduced mass and hydrodynamical mass of the cluster and daughter.

in cluster approach. Within fission approach P_0 is simply the WKB integral in the limit of parent nucleus radius and the touching distance given by

$$P_0 = \exp[-\frac{2}{\hbar}\int_{R_0}^{R_t}\sqrt{\{2\mu[V(R)-Q]\}}dR] \quad (5)$$

Results and discussion

By defining P_0 as in Eq. (5), it is possible to calculate the pre-existence probability for the complete binary spectrum of a given parent nucleus. Even for a negative Q-value system like ^{56}Ni the action integral in the overlapping region can be calculated by considering scaled Q-values. i.e., the Q-values of all the exit channels can be scaled by an uniform amount (hence the area under the potential remains the same for the two cases of actual and scaled Q-values). In Figs. 1(a) and 1(b), the pre-existence probability of all the exit channels of ^{56}Ni nucleus, calculated from Eq. (5) for the use of reduced and hydrodynamical masses are shown. It is seen that the probability decreases with increase in size of the cluster but showing prominently larger values for the α structured nuclei. It is to be mentioned here that ^{56}Ni* formed in low energy reactions are shown to have higher cross sections for the α-structured nuclei in the exit channel. Figs. 1(c) and 1(d) present the preformation probability calculated within PCM. In PCM calculations the use of reduced mass and hydrodynamical mass has not changed significantly the structure and magnitude of the probabilities, whereas in the WKB calculations though the structure has not changed the magnitude has changed considerably. Moreover the difference in magnitude between these calculations needs further investigation. The mass asymmetry motion which is to be treated separately is shown here for the complete spectrum as a part of the relative separation motion. The calculations are made for different systems in different mass regions and the results will be presented.

References

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[3] D. N. Poenaru and W. Greiner, J. Phys. G: Nucl. Part. Phys. **17** S443 (1991).