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 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 16O 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 A1 and A2 (with fixed charges Z1 and Z2, 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 56Ni 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,

\[ V(R) = a_1 R + a_2 R^2 \]  

(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.

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

(2)

The decay constant in general is defined as

\[ \lambda = PP_0 \nu_0 \]  

(3)

Here \( \nu_0 \) is the impinging frequency, P is the barrier penetration probability,

\[ P = P_{tot} = \exp\left[-\frac{2}{\hbar} \int_{R_0}^{R_s} \sqrt{2\mu[V(R) - Q]} dR\right] \]  

(4)

and \( P_0 \) is the preformation probability and is 1 in fission approach and takes different values.

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in cluster approach. Within fission approach
\( P_0 \) is simply the WKB integral in the limit
of parent nucleus radius and the touching dis-
tance given by

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

**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 \(^{56}\text{Ni}\) the action integral in the over-
lapping region can be calculated by consider-
ing 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 \(^{56}\text{Ni}\) nucleus, calculated from Eq.
(5) for the use of reduced and hydrodynamical
masses are shown. It is seen that the proba-
bility decreases with increase in size of the clus-
ter but showing prominently larger values for
the \( \alpha \)-structured nuclei. It is to be mentioned
here that \(^{56}\text{Ni}^*\) formed in low energy reactions
are shown to have higher cross sections for the
\( \alpha \)-structured nuclei in the exit channel. Figs.
1(c) and 1(d) present the preformation proba-
bility calculated within PCM. In PCM calcu-
lations the use of reduced mass and hydrody-
namical 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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