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Effect of neutron skin thickness of ^{208}Pb upon heavy cluster radioactivity

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Introduction

The studies aimed to explore the synthesis and different decay modes of super-heavy elements (SHE) are of immense interest in contemporary nuclear physics. The decay studies impart knowledge about the structure and properties of SHE. The SHE undergo *alpha*-decay, *beta*-decay, spontaneous fission, and cluster decay. Among the different decay modes, heavy-cluster radioactivity (HCR) with complementary ^{208}Pb daughter nucleus is noted to be an important decay path [1].

^{208}Pb having a large neutron-proton asymmetry entails nuclear symmetry energy. Constraining the symmetry energy and its slope parameter L(ρ_0) is quite crucial for understanding the properties of exotic nuclei, dynamics of asymmetric heavy ion reactions, and neutron star properties [2]. It is well-established that L(ρ_0) is correlated with the neutron-skin thickness (S) of ^{208}Pb [3] and facilitates to put narrow constraints on L(ρ_0). In the present work, we examine the effect of varying neutron-skin thickness of ^{208}Pb upon the heavy cluster decay half-lives of ^{282}Ds, ^{282}Cn, ^{284}Cn, and ^{290}Fl using the double folding model [4]. Further, an attempt to use HCR as a link between the neutron-skin thickness of ^{208}Pb and the slope parameter of symmetry energy L(ρ_0) is in progress.

Methodology

The key ingredient for calculating HCR half-lives is the penetrability through the interaction barrier. The penetration probability hinge upon the peculiarities of heavy cluster-^{208}Pb interaction, which is the addition of Coulomb potential, nuclear potential, and centrifugal potential. But in the present work, the centrifugal potential is not considered. The Coulomb potential can be calculated precisely, and therefore, the deterministic quantity for penetration probability is the nuclear potential. The nuclear potential is obtained using double-folded integral of renormalized M3Y nucleon-nucleon (NN) potential and density distributions of ^{208}Pb and heavy cluster as [4]

$$V_N(R) = \lambda \int dr_1 dr_2 (\rho_{1n} + \rho_{1p})(\rho_{2n} + \rho_{2p}) V_{NN} \quad (1)$$

where ρ_{in} and ρ_{ip} are the neutron and proton densities of the heavy cluster (i=1) and ^{208}Pb (i=2), respectively, which are taken as standard Fermi forms

$$\rho_{in/p}(r_i) = \rho^c_{in/p}/[1 + exp(r_i - c_i/a)].$$

The half-density radius c_i=1.07 $A_i^{1/3}$ fm and a =0.54 fm are taken from textbooks [5]. The strength of the nuclear potential λ=0.55 is taken from reaction model [4]. The M3Y NN interaction V_{NN} = 7999 exp(-4s)/4s - 2134 exp(-2.5s)/2.5s - 276(1 - 0.005E/A) $\delta(s)$

The expression for the half-life is given by

$$T_{1/2} = \frac{ln2}{\nu_0 exp[-2\int \frac{\sqrt{2\mu}}{\hbar}[V(R) - Q]^{1/2} dR]}, \quad (2)$$

The limit of the integration is determined by the turning points defined as V(r_1) = V(r_2) = Q-value of the heavy-cluster emission process, and V(R) (=V_c+V_N) is the total interaction potential. The neutron skin (S) of ^{208}Pb

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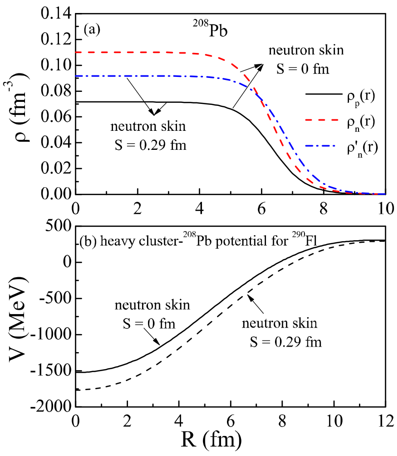

FIG. 1: (a)The neutron and proton density distribution of ^{208}Pb for two cases of neutron skin thickness (S): S = 0 fm and S = 0.29 fm. (b)heavy cluster-^{208}Pb potentials for heavy cluster emitter ^{282}Ds with S = 0 fm and S = 0.29 fm.

manifests itself in the heavy cluster-^{208}Pb interaction as well as half-lives calculations via double folding procedure. To determine the sensitivity of the interaction and half-lives to S(^{208}Pb), the half-density radius of ^{208}Pb is varied step by step while keeping its proton density distribution and other parameters unchanged. In this way, the S(^{208}Pb) is changed correspondingly and and normalization condition $\int \rho_{2n}(r)$ dr =126 was checked.

Results and discussion

Fig. 1(a) depicts the density distribution of ^{208}Pb for two cases of neutron-skin thickness of ^{208}Pb (I) S = 0 fm with standard parameters as mentioned above ($c_2 = 1.07\ A_2^{1/3}$) and (II) S = 0.29 fm (PREX-II) with $c_2 = 1.14\ A_2^{1/3}$. Because the proton density distribution is unchanged, therefore, Coulomb potential remains the same but there is a notable change in the nuclear potential. Fig. 1(b) shows that the total interaction potential V is more attractive for S = 0.29 fm case than S = 0 fm case. By varying the half-density neutron radius of ^{208}Pb, the half-lives of heavy cluster radioactive decay of ^{282}Ds, ^{282}Cn, ^{284}Cn and

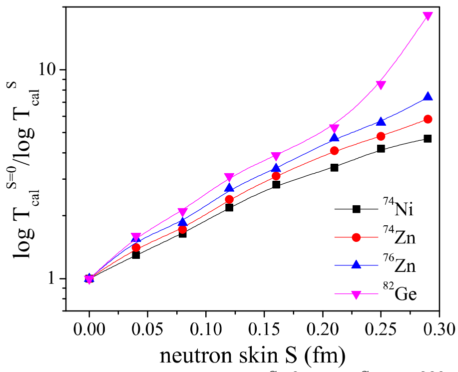

FIG. 2: Variation of log$T_{cal}^{S=0}$/logT_{cal}^{S} of ^{282}Ds, ^{282}Cn,^{284}Cn and ^{290}Fl as a function of skin thickness of ^{208}Pb.

^{290}Fl are calculated. The variation of ratio log$T_{cal}^{S=0}$/logT_{cal}^{S} with S (^{208}Pb) is shown in Fig. 2. It is noted that at S = 0 fm, the ratio is unity but it rises rapidly with increasing skin-thickness of ^{208}Pb. At higher values of S, the ratio is large, depending upon the size of heavy clusters emitted. For large clusters, this ratio is also large due to a strong density overlap between heavy clusters and ^{208}Pb. Further, the inculcation of isospin-dependent cluster-^{208}Pb potential in the above calculations is of interest. It will help to use HCR as a link between S(^{208}Pb) and L(ρ_0).

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