Analysis of Nuclear Surface Diffuseness in the Sequential Alpha Decay of ^{220}Np nucleus

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Introduction

The diffuseness parameter plays a crucial role in shaping the nuclear potential, affecting the height and position of the fusion barrier, as well as the overall dynamics of decay fragments. Small changes in this parameter can lead to significant difference in the barrier characteristics and interaction potential. This parameter is linked to the smoothness of the nuclear potential barrier, which influences the likelihood of decay through the quantum tunneling.

In this work, we focus on the sequential alpha decay chain of the ^{220}Np nucleus, which is produced in the ^{40}Ar + ^{185}Re $\rightarrow$ ^{220}Np + 5n reaction [1]. This decay chain eventually terminates at ^{208}Fr, offering an ideal case to study the impact of the nuclear surface diffuseness parameter on the decay dynamics of heavy nuclei. Our main objective is to explore the influence of the Q-value dependent surface diffuseness parameter on the decay chain of ^{220}Np, utilizing the Dynamical Cluster-decay Model (DCM) [2]. This approach, as proposed in Ref [3] allows the diffuseness parameter to vary dynamically based on the energy released at each decay step. By comparing a fixed diffuseness value with the Q-value dependent diffuseness, we aim to understand how small changes in this parameter can significantly influence decay characteristics. Our results show a decent agreement with the experimental data. In addition, we have investigated the fragmentation characteristics and the variation in the barrier lowering parameter ΔV_B in the decay chain of ^{220}Np, providing further insights into the role of diffuseness in the alpha decay mechanism.

Methodology

Based on the Quantum Mechanical Fragmentation theory(QMFT) [2], the fragmentation potential is defined as the sum of binding energies, Coulomb potential(V_c)and the proximity potential (V_p). Here the proximity potential (Prox-77) for deformed nuclei is given by:

$$V_P(s_0(T)) = 4\pi\bar{R}(T)\gamma b(T)\Phi(s_0(T)), \qquad (1)$$

where $b(T) = b_0(1 + 0.009T^2)$ is the nuclear surface diffuseness with $b_0 \approx 0.99$ fm. It is worth mentioning here that for α-decay of the recoiled heavy nucleus, the temperature T (in MeV) is related to its excitation energy E_R^* as

$$E_R^* = \frac{1}{9}AT^2 - T, \qquad (2)$$

where $E_R^* = E_R + Q_\alpha$. Here, Q_α denotes the Q value of α decay, and for the recoil energy E_R we have taken the value 12 MeV, chosen in reference to the measurements [1]. In the present work, we have analyzed the Q-value dependent diffuseness using the empirical formula [3]:

$$a_{eff} = (0.0030511Z - 0.001501N)Q^{\frac{1}{2}} + 0.15455 \qquad (3)$$

and the diffuseness parameter is obtained as:

$$b_{eff} = \frac{\pi}{\sqrt{3}}a_{eff} \qquad (4)$$

Results and Discussions

An attempt is made to analyze the effect of the diffuseness parameter on the sequential decay chain of ^{220}Np within the framework of the collective clusterization approach. To investigate this, we have used a Q-value dependent surface diffuseness parameter in DCM and compare it with the fixed diffuseness parameter ($b_0 = 0.99$ fm). First of all, Figure 1 depicts the variation in fragmentation potential for the decay of ^{220}Np, offering insights into how the potential energy changes with different fragment masses throughout the decay process. Although the

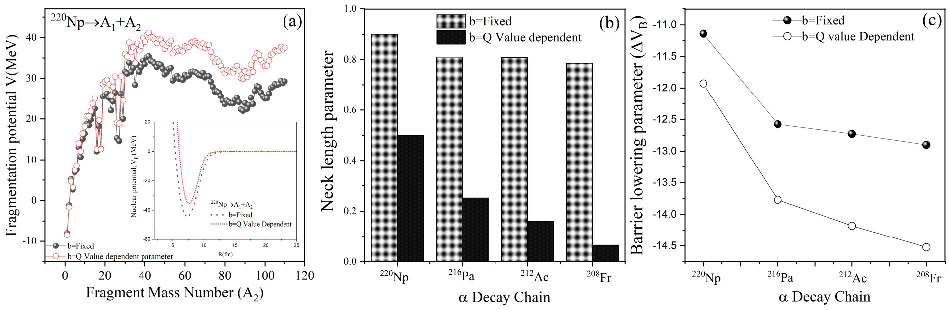

FIG. 1: (a) Fragmentation potential for decay of ^{220}Np with fixed diffuseness and Q-value dependent diffuseness. The inset shows the nuclear potential for both cases. (b) Variation of ΔR through the α- decay chain from ^{220}Np to ^{208}Fr. (c) Comparison of ΔV_B parameter for both diffuseness parameters across the decay chain.

overall structure of the fragmentation potential remains similar for both choices of diffuseness, the magnitude is higher with the Q-value dependent diffuseness. The inset of Fig. 1(a) illustrates that the nuclear potential has a deeper minima for the fixed diffuseness case,whereas it becomes shallower for the the Q-value dependent diffuseness case.

Next, we have compared the neck length parameter (ΔR) for the nuclei ^{220}Np, ^{216}Pa, ^{212}Ac and ^{208}Fr appearing in the α-decay chain. Note that ΔR is the separation distance between the surfaces of two fragments or clusters, which assimilates the deformation and neck formation effects between two nuclei. A systematic trend is observed, where ΔR is found to be largest for the fixed diffuseness ($b_0 = 0.99$ fm) and decreases significantly with the Q-value dependent diffuseness as the decay proceeds through successive α-decay channels. This suggests that for the Q-value dependent case, one can perform the calculations at near touching configuration, particularly for the lower mass residual nuclei in the α-decay chain.

In addition to this, an attempt is made to explore the barrier characteristics in the α-decay chain of ^{220}Np. It is important to mention here that the "barrier lowering parameter" ΔV_B is a built-in property of the model, which has a direct dependence on the corresponding values of ΔR used to address the available data. Note that ΔV_B is defined as the difference between the barrier height V_B, and the actual used barrier $V(R_a)$, such that $\Delta V_B = V(R_a) - V_B$. It is observed that ΔV_B is higher for the fixed diffuseness parameter ($b_0 = 0.99$ fm) and decreases with the Q-value dependent diffuseness. In summary, this study evaluates the effect of Q-value dependent diffuseness parameters on the alpha decay chains of ^{220}Np. The Q-value dependent diffuseness parameter, when implemented in DCM, significantly alters the fragmentation potential's magnitude but not its structure. The neck length (ΔR) decreases significantly for the Q-value dependent diffuseness, indicating that the decay involves smaller spatial separations thereby suggesting the feasibility to operate near touching configuration. It will be of further interest to investigate the relevance of Q-value diffuseness parameter on a larger set of radioactive and synthesized nuclei.

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