Attempt to connect the nuclear charge radii with the experimental α decay data for superheavy nuclei

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Abstract. Significant progresses have been made so far for the synthesis of the heaviest elements, while the knowledge of them appears to be quite limited even when it comes to basic properties, e.g., their size. On the other side, the observation of α decay chains is the main tool to identify the newly produced elements. In this report, we propose to make use of the available experimental α decay data to extract the nuclear charge radii of superheavy nuclei. Within the density dependent cluster model, the nucleon density distribution of the target nucleus is determined by exactly reproducing the measured α decay half-life of its parent, finally leading to the nuclear radii. Encouraged by the agreement between theory and experiment for heavy nuclei, we extend the study to the region of superheavy nuclei as well.

1 Background and motivation

With the advent of improved facilities and technologies, a great deal of experimental efforts have been devoted to synthesize the superheavy nuclei (SHN), leading to the makeup of nuclidic chart up to $Z = 118$ [1, 2]. The α decay chains are not only taken as the main source to identify the newly synthesized SHN, but also provide insight knowledge about their properties. As well known, there are available methods to measure the nuclear charge radius such as particles scattering on the target nuclei, Kα X rays, measurements of transitions energies in muonic atoms and optical isotopes shifts [3]. Unfortunately, the detection on the SHN radii is still difficult using these methods due to short lifetimes and tiny cross sections of heaviest nuclei. It is therefore interesting to employ an alternative approach using the available experimental α decay data to extract more information on structural properties, e.g., the nuclear charge radii, for superheavy nuclei. In fact, α decay has been taken as a tool to recognize the nuclear radii at an early stage of nuclear physics, despite the rough assumptions. Owing to the advanced experimental facilities and theoretical approaches, improved experimental data have been accumulated for the α decay process [1, 2, 4] and considerable progresses have also been made for the α decay calculations [5–13]. With these in mind, we propose to establish a bridge between the nuclear radii and the experimental α decay data. The main logic of the present model will be presented with initial results in the following section.

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2 Brief introduction of theoretical approach and results

Given that the α decaying nucleus is pictured as an α particle interacting with an axially symmetric deformed core nucleus, the total α-core potential is composed of the nuclear and Coulomb terms,

$$V(r,\theta) = \lambda V_N(r,\theta) + V_C(r,\theta), \tag{1}$$

where θ is the orientation angle of the emitted α particle with respect to the symmetric axis of the core, and λ is the renormalization factor for the depth of nuclear potential. Based on the double folding integral, the nuclear and Coulomb potentials can be constructed as [14]

$$V_{NorC}(\mathbf{r},\theta) = \iint d\mathbf{r_1}\, d\mathbf{r_2}\, \rho_1(\mathbf{r_1})\rho_2(\mathbf{r_2}) \\ \upsilon(\mathbf{s} = |\mathbf{r_2} + \mathbf{r} - \mathbf{r_1}|), \tag{2}$$

where υ(s) denotes the M3Y-Reid type nucleon-nucleon interaction and the standard proton-proton Coulomb interaction for nuclear and Coulomb potentials, respectively. Besides the widely-used Gaussian form ρ_1 for the α particle, the mass and charge density distributions of the daughter nucleus are supposed to behave in the deformed two parameter Fermi (2pF) form. Once the total α-core interaction potential is confirmed, the final decay width can be obtained via the modified two-potential approach plus the averaging procedure [7, 15]. Undoubtedly, the density distribution $\rho_2(r_2)$ is an important input for this whole calculation leading to the final α decay half-lives. In turn, one can get the fact that the parameters of ρ_2 can be determined by exactly reproducing the experimental α decay half-lives. Subsequently, the required root-mean-square charge radius can be achieved via the corresponding charge density distribution. In this way, the rms nuclear charge radii

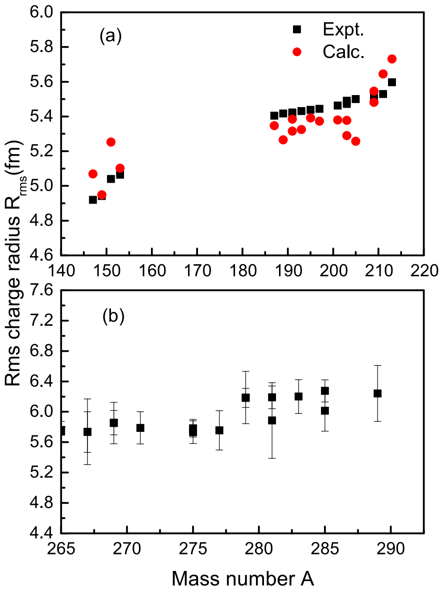

Figure 1. (a) Comparison of our extracted rms nuclear charge radii with the available experimental values for odd-*A* nuclei with $Z = 65-87$. (b) Predicted rms charge radii of odd-*A* isotopes with $Z = 102-115$, along with error bars coming from the uncertainties of the experimental α decay data.

is linked to the experimental α decay data, and more details can be found in Ref. [16]. Initially, we have paid attention to the odd-*A* nuclei with available measured decay data and related radii values. The upper panel (a) of fig. 1 represents the detailed comparison of our extracted nuclear charge radii with measured ones, which indicates that the satisfactory agreement between theory and experiment has been reached. Encouraged by this, we extend the study to heaviest odd-*A* nuclei, as shown in the lower panel (b) of fig. 1. It is shown that the present approach may provide an alternative way to pursue the fundamental feature, namely nuclear radii, for those unmeasured nuclei.

3 Summary

In summary, the rms nuclear charge radii of target nuclei have been extracted from the experimental α decay data of their parents via the density-dependent cluster model. During this process, the density distribution of daughter nucleus is determined by exactly reproducing the measured half-life of α decaying nucleus, resulting in the focused nuclear charge radii. It is found that our presently deduced nuclear radii are in good agreement with available experimental data for odd-*A* nuclei with $Z = 65-87$. The predictions on nuclear charge radii are then made for odd mass superheavy nuclei, which may be expected to give a possible way to recognize this fundamental property of SHN.

This work is supported by the National Natural Science Foundation of China (Grant No. 11605089), by the Natural Science Youth Fund of Jiangsu Province (Grant No. BK20150762), and by the Fundamental Research Funds for the Central Universities (Grant No. 30916011339).

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