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ALPHA DECAY HALF-LIVES FOR SUPER-HEAVY NUCLEI WITHIN A GAMOW-LIKE MODEL[*]

A. Zdeb, M. Warda, K. Pomorski

Department of Theoretical Physics, Maria Curie-Skłodowska University
pl. Marii Curie-Skłodowskiej 1, 20-031 Lublin, Poland

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The simple two-free-parameter phenomenological formula derived in A. Zdeb, M. Warda, K. Pomorski, *Phys. Rev.* **C87**, 024308 (2013) for alpha and cluster decays is applied to predict alpha radioactivity half-lives of super-heavy isotopes. Nuclei with proton number $100 \leq Z \leq 122$ and neutron number $150 \leq N \leq 192$ are considered.

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1. Introduction

Phenomenological model of alpha and cluster decay processes, based on the Gamow theory, was developed in Refs. [1, 2]. This two-free-parameters model reproduces well the experimental data for cluster and alpha decay half-lives of even and odd nuclei with the atomic number $84 \leq Z \leq 110$. Within this method, the probability of tunnelling through the potential barrier is calculated using one-dimensional WKB approximation. Quite good accuracy was achieved in this region in comparison with other formulas [3, 4].

The existence and decay properties of not yet observed nuclei are one of the most fundamental problems in nuclear physics. The predictions of the decay modes and the half-lives of the super-heavy elements might be helpful in identification of new synthesized isotopes. Alpha decay and spontaneous fission are the dominant processes of disintegration of super-heavy nuclei. Simple phenomenological model, presented in this paper, enables to predict the half-lives of super-heavy alpha emitters in a large, not yet measured region of nuclei.

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2. Model

In the quantum tunnelling theory of alpha emission, one can express the decay constant λ as a product of the probability of tunnelling through the potential barrier and the number of assaults per time unit of emitted particle.

In our model, the barrier penetration probability is calculated using one-dimensional WKB approximation

$$P = \exp\left[-\frac{2}{\hbar}\int\limits_{R}^{b}\sqrt{2\mu(V(r)-E_k)}dr\right], \tag{1}$$

where μ is a reduced mass of alpha particle, $R = r_0[(A-4)^{1/3}+4^{1/3}]$ is the spherical square well radius, and $b = \frac{2(Z-2)e^2}{E_k}$ is the second turning point radius (Fig. 1). The number of assaults per time-unit is estimated from the quantum-mechanical ground-state frequency of the alpha particle in the spherical square well

$$\nu = \frac{\pi\hbar}{2\mu R^2}. \tag{2}$$

In this approach, the expression for alpha decay half-lives takes the form

$$T_{1/2} = \frac{\ln 2}{\lambda}10^h. \tag{3}$$

The least-square fit of the radius constant r_0 was performed to the experimental data for the 354 alpha decays taken from [5] for nuclei with $Z \geq 84$. To reproduce the experimentally observed longer $T_{1/2}$ of odd or odd–odd

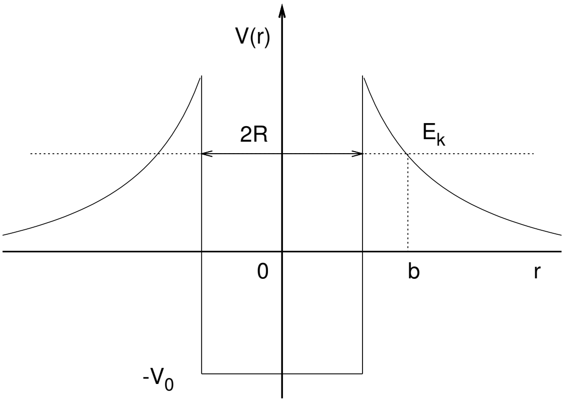

Fig. 1. Schematic plot of the potential energy of the decaying nuclei.

nuclei, an additional adjustable constant h (*hindrance factor*) is introduced in Eq. (3). The values of these parameters are as follows

$$r_0 = 1.21\ \mathrm{fm}\,, \qquad h = h_p = h_n = 0.216\,, \qquad h_{np} = 2h\,.$$

The kinetic energy of the emitted alpha particle is deduced from the decay reaction Q-value, which was calculated using the Lublin–Strasbourg Drop mass formula [6, 7]

$$\begin{aligned} M_{\mathrm{LSD}}(Z,N,\mathrm{def}) \;=\; & ZM_H + NM_n - 0.00001433Z^{2.39} \\ & -15.4920\left(1-1.8601I^2\right)A \\ & +16.9707\left(1-2.2938I^2\right)A^{2/3} \\ & +3.8602\left(1+2.3764I^2\right)A^{1/3} \\ & +0.70978\frac{Z^2}{A^{1/3}} - 0.9181\frac{Z^2}{A} \\ & +E_{\mathrm{congr}}(Z,N) + E_{\mathrm{micro}}(Z,N,\mathrm{def})\,. \end{aligned} \tag{4}$$

The mass is given in MeV. The congruence energy is of the form [9]: $E_{\mathrm{congr}} = -10\ \exp\{-4.2\ |(N-Z)/A|\}$ MeV. The ground state microscopic corrections E_{micro} are taken from Ref. [9] for all considered nuclei.

3. Results

The formalism presented in the previous section was used to investigate half-lives of super-heavy nuclei. The alpha decay half-lives, calculated using the discussed model, for emitters with proton numbers in the region $100 \leq Z \leq 122$ are presented in Figs. 2–5 and compared to the available experimental data [5, 8]. One can observe decreasing alpha decay half-lives with increasing atomic number, which is in agreement with the observed experimental systematic.

A similar behaviour of half-lives along different isotopic chains can also be found. The local maximum appears for $N = 162$ in even-Z and for $N = 163$ in odd-Z nuclei. It is connected with increasing of stability in the region of the so-called deformed magic number of neutrons. The half-lives for alpha decay grow with the neutron number increasing beyond $N = 165$ in all elements. In the heaviest isotopes, it may even reach $T_{1/2} = 10^{10}$ s. In these nuclei, alpha decay would be irrelevant decay channel as spontaneous fission may have much shorter half-lives. Our extrapolation indicates that most of isotopes with proton numbers $Z = 120 \div 122$ are under the experimental limit $T_{1/2} = 10^{-5}$ s of possible detection. Our calculations give smaller half-lives in these nuclei than obtained in the other methods.

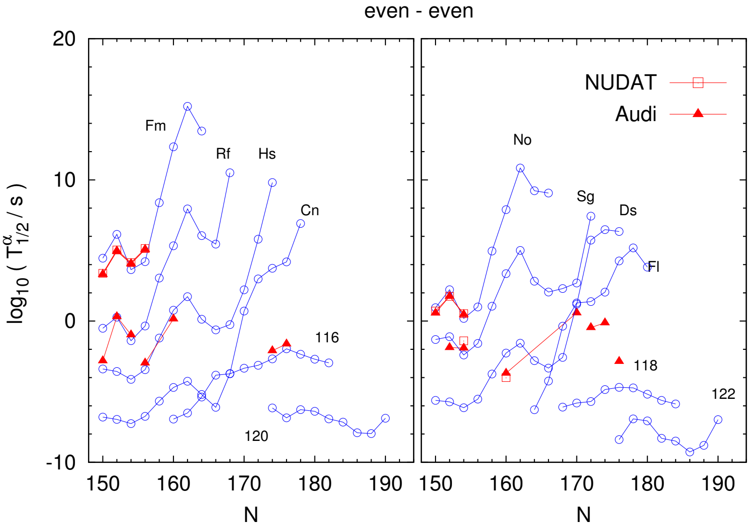

Fig. 2. Alpha decay half-lives of even–even nuclei as a function of the neutron number. Theoretical values, marked by circles (blue), are compared to the experimental data taken from [5] (squares (red)) and [8] (triangles (red)).

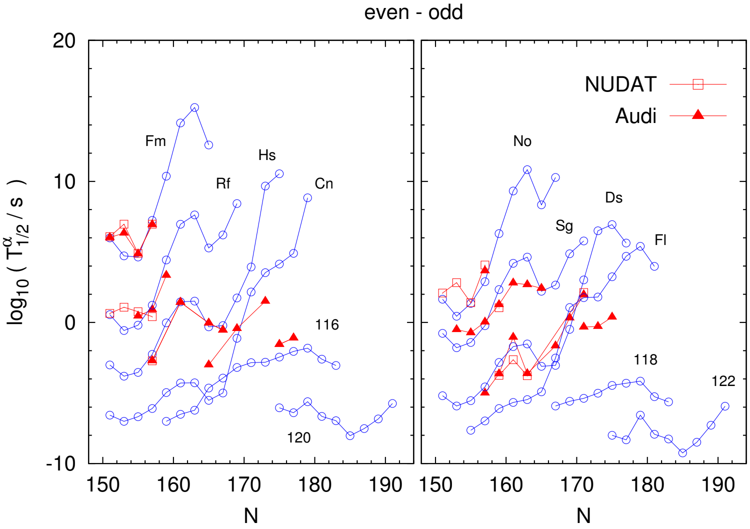

Fig. 3. The same as in Fig. 2, but for even–odd emitters.

Predictions of alpha emission half-lives, made using presented model, are comparable with results obtained within microscopic approach [10] and the semi-empirical Viola–Seaborg-like formula [11]. The deviations between measured and calculated alpha decay half-lives in most cases do not exceed 2 orders of magnitude.

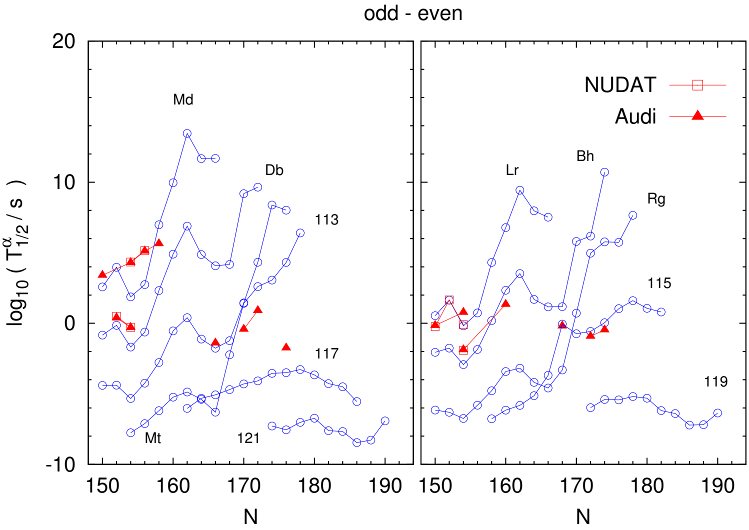

Fig. 4. The same as in Fig. 2, but for odd–even emitters.

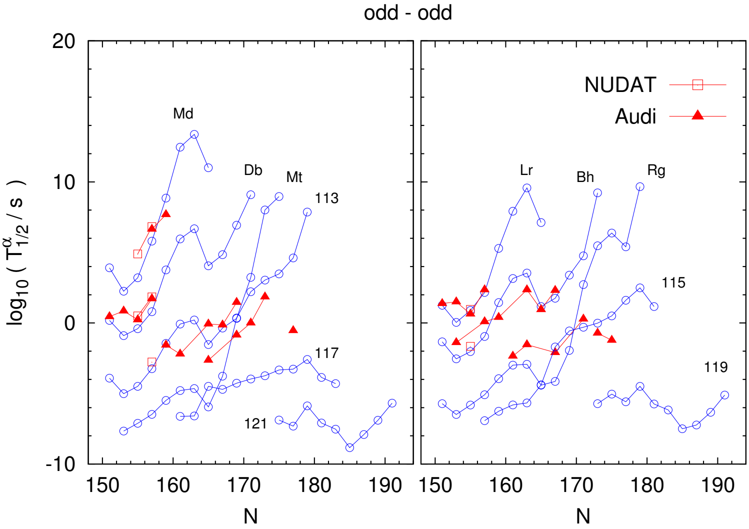

Fig. 5. The same as in Fig. 2, but for odd–odd emitters.

4. Conclusions

The simple analytical formula, found for the alpha and cluster decays, was applied to predict α-decay half-lives of 497 nuclei in the atomic number range $100 \leq Z \leq 122$ for even–even, even–odd, odd–even and odd–odd systems. The model reproduces alpha emission half-lives using only two adjustable parameters: radius constant and hindrance factor. Half-lives of investigated isotopes have local maxima in the regions of deformed magic numbers of neutrons. Obtained results reveal quite close agreement between the experimental and calculated α-decay half-lives for super-heavy nuclei. The accuracy of these estimations might be improved by performing fitting procedures of adjustable parameters only in the considered region.

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