



Ідентифікатор подання: 25

Тип: Секційна доповідь

Empirical relations for α -decay half-lives: the effect of deformation of daughter nuclei

понеділок, 26 травня 2025 р. 15:30 (15 хвилин)

Empirical relations for α -decay half-lives: the effect of deformation of daughter nuclei

V. Yu. Denisov

¹INFN Laboratori Nazionali di Legnaro, Legnaro, Italy²Faculty of Physics, Taras Shevchenko National University of Kiev, Kiev, Ukraine

α -decay plays an important role in nuclear physics. The first empirical expression for α -decay half-lives was proposed in 1911 by Geiger and Nuttall as a relation between the decay constant and the range of α -particles in air [1, 2]. In its modern form, the Geiger-Nuttall law is:

$$T_{1/2} = a \frac{Z}{\sqrt{Q}} - b$$

tag1 Here, $T_{1/2}$ is the half-life in seconds, Z is the number of protons in the parent nucleus, Q is the α -decay Q -value in MeV, and a and b are coefficients found by fitting experimental data. The experimental values for α -decay half-lives can be taken from Ref. [1]. The Q -value for the α -transition between the ground states is calculated using the masses of atomic nuclei [2]. Since 1911, many extensions of the Geiger-Nuttall expression for α -decay half-lives have been proposed. The original expression contains two fitting parameters for the full set of nuclei. Later, a formula with two general parameters and one parameter varying for even-even (even Z -even N , where N is the number of neutrons), even-odd, odd-even, and odd-odd nuclei was proposed [3]. This formula has five fitting parameters, as three additional parameters are introduced for even-odd, odd-even, and odd-odd nuclei. The development of expressions for α -decay half-lives follows two approaches. One approach uses different fitting parameters for various sets of nuclei. For example, the Geiger-Nuttall relationship can be applied with four sets of parameters for even-even, even-odd, odd-even, and odd-odd nuclei, resulting in eight fitting parameters. The other approach involves more complex expressions with additional terms depending on Z , Q , and A , where A is the number of nucleons in the parent nucleus, as detailed in Ref. [4]. Often, these approaches are combined. The influence of the deformations of daughter nuclei on α -decay half-lives has not been considered in empirical expressions. Therefore, it is valuable to include a term dependent on the deformation of the daughter nucleus in the empirical expression for α -decay half-lives. The main goal is to discuss new empirical expressions for α -decay half-lives that account for deformation. Additionally, the empirical expression for α -decay half-lives related to transitions from the ground state to the lowest 2^+ state of even-even nuclei is discussed. This expression is linked to the one for ground-state transitions, as the nuclear structure in the 2^+ and ground states is nearly identical for α -transitions. The differences arise only from the energy and angular momentum of the α -transitions. The first empirical relation introduced here is:

$$T_{1/2} = a \frac{Z}{\sqrt{Q}} - b - c(A-4)^{1/6} Z^{1/2} - dA^{1/6} \sqrt{l(l+1)}/Q - e(k\beta)^{1/2} \frac{Z}{\sqrt{Q}}$$

tag2 The first two terms correspond to the Geiger-Nuttall expression (see Eq. (1)). The third term, introduced in Ref. [5], improves decay half-lives. The fourth term, also from Ref. [5], accounts for transitions between ground states with different spin-parity characteristics, where $l = l_{\min}$ is the minimal angular momentum for the α -transition. This term significantly enhances the description of α -decay half-lives in odd- A and odd-odd nuclei with varying spin-parity characteristics. The parity term from Ref. [22] is omitted to reduce the number of fitting parameters. The fifth term in Eq. (2) accounts for the reduction of α -decay half-lives due to the deformation of the daughter nucleus. This novel term has not been previously discussed in empirical relationships. Here, β is the quadrupole deformation parameter of the daughter nucleus surface radius, defined as $R(\theta) = R_0[1 + \beta Y_{20}(\theta)]$, where R_0 is the radius of the spherical nucleus, and $Y_{20}(\theta)$ is the spherical harmonic function. The parameter $k = 2$ for prolate nuclei and $k = -1$ for oblate nuclei. The values of β can be obtained from Refs. [6-8]. Note that β values differ slightly across these references, affecting the coefficients a , b , c , d , and e . A new type of empirical relation for α -decay half-lives introduced here is:

$$T_{1/2} = a \frac{Z}{\sqrt{Q}} - b \left(\frac{A\sqrt{Q}}{Z} \right)^{1/6} - cA^{1/6} Z^{1/2} - dA^{1/6} \sqrt{l(l+1)}/Q - e(k\beta)^{1/2} \frac{Z}{\sqrt{Q}}$$

tag3 The difference between Eq. (2) and Eq. (3) lies in the second term. Both equations have the same number of fitting parameters. The new term, dependent on the quadrupole deformation of the daughter nucleus, reduces the root-mean-square (rms) error of the decimal logarithm of decay half-lives by up to 23%. This is particularly significant for even-even nuclei, where decay half-lives and spin-parity characteristics are known with high precision, allowing for accurate fitting.

Different sets of deformation parameters lead to varying rms errors and parameter values due to differences in quadrupole deformation half-life descriptions.

The new empirical expression (Eq. (3)) provides high precision in describing experimental data. Additionally, an expression for the decay half-life is given for even-even nuclei, covering transitions from the ground state to both the ground and the lowest 2 excited states.

1. <https://www.nndc.bnl.gov/nudat3/>
2. F. G. Kondev et al. Chin. Phys. C 45 (2021) 030001
3. V. E. Viola, G. T. Seaborg. J. Inorg. Nucl. Chem. 28 (1966) 741
4. V. Yu. Denisov. Phys. Rev. C 110 (2024) 014605
5. V. Yu. Denisov, A. A. Khudenko. Phys. Rev. C 79 (2009) 054614
6. P. Möller et al. At. Data Nucl. Data Tables 109–110 (2016) 1
7. N. Wang et al. Phys. Lett. B 734 (2014) 215
8. S. Goriely, N. Chamel, J. M. Pearson. Phys. Rev. C 88 (2013) 061302

Author: ДЕНИСОВ, Віталій Юрійович (Національний інститут ядерної фізики, Національна лабораторія Леньяро, Леньяро, Італія та Національний університет імені Тараса Шевченка, Київ, Україна)

Доповідач: ДЕНИСОВ, Віталій Юрійович (Національний інститут ядерної фізики, Національна лабораторія Леньяро, Леньяро, Італія та Національний університет імені Тараса Шевченка, Київ, Україна)

Тип засідання: Теоретична ядерна фізика

Класифікація за напрямком: Теоретична ядерна фізика