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Nuclear isospin effect on α-decay half-lives

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Abstract

The α-decay half-lives for the even–even, even–odd, odd–even and odd–odd of 356 nuclei in the range $52 \leq Z_p \leq 118$ have been studied within the analytical formula of Royer and also within the modified analytical formula of Royer. We calculated the new coefficient of the Royer by fitting 356 isotopes. Also, we considered the Denisov and Khudenko formula and obtained the new coefficient for the modified Denisov and Khudenko formula. We calculated the standard deviation and the average deviation. Analytical results are compared with the experimental data. The results are in better agreement with the experimental data when the effect of the isospin considered for the parent nuclei.

Keywords: α-decay; Half-life; Isospin; Angular momentum

1. Introduction

The alpha decay mode is usually used for the prediction of heavy nuclei and unknown superheavy nuclei SHN [1–5]. The simple empirical relations between alpha-decay half-lives and decay energies are also presented by several authors [6–31]. Viola and Seaborg proposed a simple formula for the prediction of alpha half-lives, which is based on Gamow model [7]. In 1992, a universal scaling law for alpha decay half-lives of even–even parents, by using the Geiger–Nuttall

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law and the $Z_d Q^{-1/2}$ dependence where Z_d is the charge number of the daughter nucleus, was predicted by Brown [8]. A semi empirical relationship, on the grounds of the fission theory for alpha decay in each group of the nuclei (e–e, o–e, e–o and o–o), was proposed by Poenaru and Ivascu [32]. Zhang et al. [33] investigated systematically the experimental α decay energies and half-lives to extract α particle pre-formation in heavy nuclei and proposed formulas for the pre-formation factors that can be used to guide microscopic studies on pre-formation factors and perform accurate calculations of the alpha decay half-lives. Poenaru et al. [34] computed the half-lives of α decay of transuranium nuclei including superheavies by three methods: a semi-empirical formula taking into account the magic numbers of nucleons, the analytical super asymmetric fission model and the universal curves. Santhosh and Nithya [35] analyzed decay modes of isotopes of the superheavy element $Z = 123$ within the range $297 \leq A \leq 307$ by comparing the alpha decay half-lives with the spontaneous fission half-lives. Sets of simple relations for evaluation of the half-lives of α transition between the ground states of parent and daughter nuclei for half-lives in 344 α emitters were discussed by Denisov and Khudenko [36]. A new empirical formula for the calculations of alpha decay half-lives by introducing isospin asymmetry, I, recently reported by Akrawy and Poenaru [37], which is based on the Royer relationship. The aim of this work is to determine the alpha-decay half-lives of even–even, even–odd, odd–even and odd–odd isotopes within the modified analytical expressions which depends on the angular momentum and nuclear isospin asymmetry and the results obtained are compared with experimental data and other theoretical model such as Royer formula [38]. This article is organized as follows:

In Section 2, we present the details of the analytical formula of Royer and the modified analytical isospin dependent formula of Royer for the calculation alpha decay half-lives, also, we added the Denisov and Khudenko formula (DKF) and the modified Denisov and Khudenko formula (MDKF) and presented in a new table. Section 3, includes the numerical results and discussions on the alpha-decay half-lives of the light, heavy and superheavy nuclei. Finally, conclusions are given in Section 4.

2. The analytical formulas for α-decay half-lives

2.1. The Analytical Royer Formula (RF)

In 2010, Royer [38,39] proposed empirical expressions for alpha decay half-lives of the even–even (e–e), even–odd (e–o), odd–even (o–e) and odd–odd (o–o) nuclei, which depend on the angular momentum of the alpha particle for, is given by

$$\log_{10} T_{1/2}^{RF} = a + bA^{1/6}\sqrt{Z} + c\frac{Z}{\sqrt{Q}} + d\frac{ANZ\left[\ell\left(\ell+1\right)\right]^{\frac{1}{4}}}{Q} + eA\left[1-(-1)^{\ell}\right], \tag{1}$$

where A, Z and N are the mass, charge and neutron number of the parent nucleus, respectively, which provide general guidance for the study of the α-logarithmic half-life time. Q-value is the decay energy in MeV units, ℓ is the orbital momentum of emitted α particle and a, c, d and h free parameter coefficients. Instead of using original set of parameters we have improved the relation by least square fitting method of α-decay data of 356 nuclei and the new values of the parameters are given in Table 1.