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Radioactivity effect on the shape of even-even nuclei for uranium and thorium series

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ABSTRACT

The purpose of present work is to study the relationship of the deformed shape of the nucleus with the radioactivity of nuclei for (Uranium-238 and Thorium-232) series. To achieve our purposes we have been calculated the quadruple deformation parameter (β_2) and the eccentricity (e) and compare the radioactive series with the change of the (β_2) and (e) as indicator for the changing in the nucleus shape with the radioactivity.

To obtain the value of quadruple deformation parameter (β_2), the adopted value of quadruple transition probability B ($E2$; $0^+ \rightarrow 2^+$) was calculated from Global Best fit equation. While the eccentricity (e) was calculated from the values of the minor and major ellipsoid axis's (a & b).

From the results, it is obvious that the radioactive nuclei by its decay for both series, try to achieve more stability by changing its shape towards the perfect sphere shape.

Introduction

The shape of the nucleus was first assumed to be spherical, but in 1924Wolfgang Pauli proposed that an excited nucleus could exist in different shapes. Then in 1936 Bohr and Fritz Kalckar suggested that the shapes of nuclei could be determined by measuring photons of a gamma-ray emitted by an excited nucleus as it de-excites. Over the later seventy years, we are still studying the shapes of nuclei just as they proposed, via gamma-ray spectroscopy [1].

Since a nucleus wanted to be in the ground state, it needs to get overcome its spin and excess energy. Particle loss occurs first, where charged particle giving out (alpha particles and protons) is held up by the Coulomb barrier. Only (8–10) MeV are carried out from the excitation energy with each emitted neutron. Most of the nucleus excitation energy was also if one particle emission, while only a small amount of angular momentum. Therefore gamma-ray emission occurs to release this angular momentum and the remaining energy [1].

A radioactive decay process is a series chain of decay, in another word, the decay of single nucleus leads to another nucleus which is also has a radioactive, and this chain continues until a steady nucleus is achieved [2].

All known natural radionuclides are grouped in three families having as the nucleus at the start of the chain. These are thorium-232, uranium-238 and uranium-235. All isotopes of these series are radioactive and the above three are the heaviest ones with a half-life is very long [2].

The mass numbers of each isotope in these series have values of the style A = 4k, A = (4k + 2) and A = (4k + 3), with k integer [2].

In our study, two radionuclides family series are adopted since their elements decay have even-even number for the mass and the atomic number which is thorium-232 and uranium-238, while the third family started its decay with odd-even for the mass and the atomic number which makes it hard to calculate the transition energy to calculate the nuclear deformation.

The deformation parameter (β_2) is basic descriptors of the nuclear equilibrium shape and structure [3]. The simplest deformations are called quadruple deformations where the nucleus can take either a prelate shape or oblate shape [4].

Theoretical part

The equations that used in this research to calculate the deformation degree are described as follow:

1. Quadruple Deformation Parameter (β_2)

The deformation parameter (β_2) represents the amount of the nuclear quadruple deformation (elongation or flattening) and also refers to the deviation of the nuclear shape from axial symmetry [5,6].

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$$\beta_2 = \frac{4\pi}{3ZR_o^2}\left[\frac{B(E2)\uparrow}{e^2}\right]^{1/2} \quad (1)$$

where Z is the atomic number of nuclei and is the average radius nuclear which can be calculated from this equation [7]:

$$Ro^2 = 0.0144\ A^{2/3}\text{barn} \quad (2)$$

where A is the mass number of a nucleus and B (E2) ↑ is the reduced electric quadruple transition probability for E2-transition $0^+ \to 2^+$ which is calculated from [7]:

$$B(E2)\uparrow = \frac{2.6Z^2}{E_{\gamma_0} A^{\frac{2}{3}}} \quad (3)$$

where E_{γ_0} is the energy of the Gamma ray transitions in keV units.

2. Eccentricity (e)

Eccentricity (e) is a parameter related to each conic section. It is able to think of as a measure of how much the conic section deviates from being spherical. The eccentricity (e) which refers to radioactivity and calculated from this equation [8]:

$$e = \sqrt{1-\left(\frac{a}{b}\right)^2} \quad (4)$$

where (a) and (b) are the small (minor) and the large (major) ellipsoid axes respectively. These parameters can be calculated from the following equations [9].

$$Q_0 = 2/5Z\ (b^2 - a^2) \quad (5)$$

$$\delta = 0.3(b^2 - a^2)/2 < r^2 > \quad (6)$$

where

$$< r^2 > = (b^2 + 2a^2)/5 \quad (7)$$

From Eqs. (5)–(7) we obtained:

$$a = \left[\frac{<r^2>}{3}\left(5 - \frac{2\delta}{0.3}\right)\right]^{1/2} \quad (8)$$

$$b = [5 < r^2 > -2a^2]^{1/2} \quad (9)$$

Where $< r^2 >$ is the mean-squared charge distribution radius average was evaluated using the following expression.

$$< r^2 > = 0.6[1.2A^{1/3}]^2 (A > 100) \quad (10)$$

The quadruple deformation parameter (δ) represents the measure of nucleus shape deviation from spherical of the nucleus could be calculated by the formula [9].

$$\delta = \frac{0.75Q_o}{(< r^2 > Z)} \quad (11)$$

where Q_0 is the intrinsic quadruple moment which gives a quantity of the charge distribution of the nucleus and measured by using this equation:

$$Q_o = \left[\left(\frac{16\pi}{5}\right)\frac{B(E2)\uparrow}{e^2}\right]^{1/2} \quad (12)$$

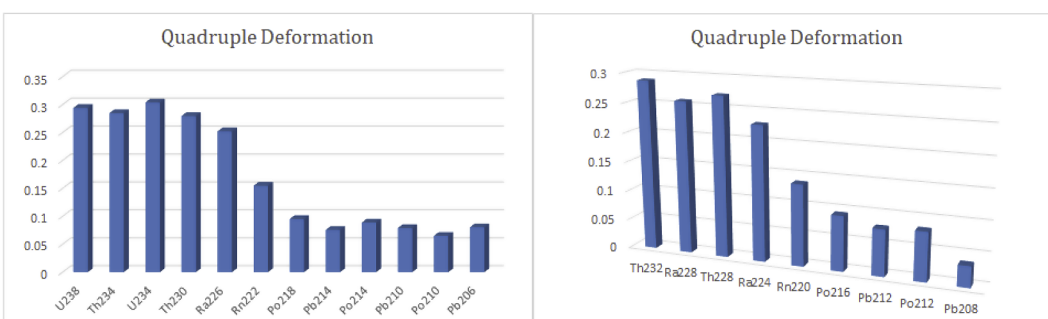
From this equation, we can show that the unit of the intrinsic quadruple moment Q_0 is a barn (b) [10].

Results and discussion

The nuclei deformation is calculated with help of Quadruple deformation parameter (β_2) and the eccentricity (e) as follow:

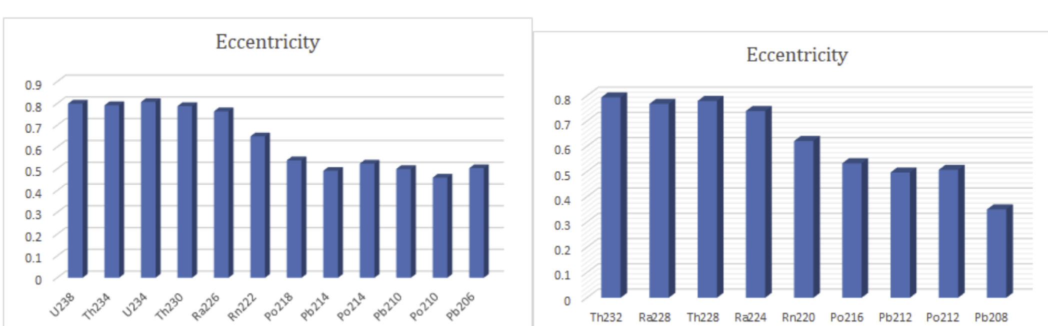
1. Quadruple Deformation Parameter (β_2)

The study of the relationship of nucleus quadruple deformation parameter (β_2) with the radioactivity of nuclei for (Uranium-238



(a) (b)

Fig. 1. The calculated values forquadrupledeformation(β_2), (a) ^{238}U series (b) ^{232}Th series.



(a) (b)

Fig. 2. The calculated values for eccentricity(e), (a) ^{238}U series (b) ^{232}Th series.