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The relationship of Nuclear Decay Methods (alpha and beta) Particles with the Nuclear Deformation for Nuclei inUranium-238 and Thorium -232 Series

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Abstract

In this work, a study of the relationship of the decay mode (alpha and beta) emission and the deformed shape of even-even nuclei in uranium -238 and thorium -232 series is presented. To achieve our purpose the quadrupole deformation parameter (β_2) (which refers to the shape of nuclei) and eccentricity (e) (represented the radioactivity) have been compute for each nuclei which decay by (alpha or beta) particles emission in each series. The results of deformation parameter show that the deformation on the shape of nuclei (near from spherical shape) for nuclei which decay by beta particles emission is lower than the deformation on the shape of the nuclei which decay by alpha particles emission for two series. In addition, we shows that the effected of deformation parameter greeter than the effected of eccentricity by the type of decay (alpha & beta) emission. Finally, an empirical equation has been extracted from plotting deformation parameter as a function to eccentricity, which can be used to calculate the defamation parameter for any nuclei has eccentricity value.

*Keywords:*radioactivity, alpha decay, beta decay,quadrupoles transition probability,quadrupole deformation parameter, eccentricity,ellipsoid axis.

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1. Introduction

The nucleus of atomic is the weighty, small and core of atom that consist of nucleons. These nucleons are numbers of protons or neutrons, which clustered in two groups. These protons and neutrons are independently distributed over certain energy states, and they are held together by their common interactions. The nucleons can be excited in various energy levels for a very short time. Often, it decays or becomes de-excited by emitting electromagnetic radiation in the form of (γ-ray) transitions to states with lower energies. [1]This phenomenon is called radioactivity.

Radioactivity of nucleus comes from their instability. Which depends on, the balance between the atomic and neutrons number. For nuclides, which have mass number, greater than 210 are unstable. There are three methods of decay: alpha (α), beta (β) and gamma (γ-ray). In theory, nuclei with atomic numbers greater than 83 are probable to undergo an alpha decay. [2]

The deformation comes from the way that valence nucleons arrangement themselves in an unfilled shell, in other words the deformation occurs only when both proton and neutron shells are somewhat full. [3] In the cluster, decay process the important character is shell nuclear deformations. In order to look for the effected of the shape of the nuclide in the radioactive decay processes we intend to investigate the relationship of spherical shape as well as quadrupole deformation (β_2) on the behavior of possible fragmentations of the decaying parent nucleus. [4]

The nuclides^{238}U, ^{235}U and ^{232}Th, are the three heavy origins of the three natural radioactivity chains, which go to the stability through a series of α and β decays which end by three lead stable isotopes [5]

$$^{238}U \rightarrow {}^{206}Pb(A = 4n + 2)$$

$$^{235}U \rightarrow {}^{207}Pb(A = 4n + 3)$$

$$^{232}Th \rightarrow {}^{208}Pb(A=4n)$$

2. Theoretical Part

2.1. 1-Quadrupole Deformation Parameter (β_2)

The deformation parameter(β_2) refers to the deviation of the nuclear shape from axial symmetry, as well as represents the amount of the (flattening or elongation) and related with reduced quadrupole transition probability for E2-transition ($0^+ \rightarrow 2^+$) B (E2) so it can computed from the following equation: [6] [7]

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

Where:

Z: is the atomic number of nuclei.

R_o^2:The average radius nuclear could be calculated by using this equation. [8]

$$R_0^2 = 0.0144\ A^{2/3}\ barn (2)$$

Where:

A: is the mass number of a nucleus

B (E2) ↑ : is the reduced electric quadrupole transition probability for ($0^+ \rightarrow 2^+$) transition, which calculated from the Global Best Fit systematic by using the formula: [8]

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

Where:
E_{γ_0}: is the energy of the gamma ray transitions in Kev units.
2-Eccentricity (e)
The eccentricity (e) denotes to the radioactivity and connected with each conic section. The deviation of the conic section from spherical shape can be measured by eccentricity, which calculated from this equation: [9]

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

Where
a: (minor) the small ellipsoid axis
b: (major) the large ellipsoid axis
Minor and major ellipsoid axis can be calculated by using these formulas. [10]

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

$$b=[5<r^2>-2a^2]^{1/2} \quad (6)$$

Where:
$<r^2>$: The mean-squared charge distribution radius average which measured by: [11]

$$<r^2>=0.6\left[1.2A^{1/3}\right]^2 \quad (A>100) \quad (7)$$

(δ): The quadrupole deformation parameter refers to the amount of a deviation of nucleus shape from spherical shape and depends on the value of intrinsic quadrupole moment (Q_0) as explained in this equation: [11]

$$\delta=\frac{0.75Q_o}{(<r^2>Z)} \quad (8)$$

The intrinsic quadrupole moment, provides a distribution of the charge nucleus (deviation from spherical similarity), and gives an information about the degree of deformation in the shape of the nucleus. The intrinsic quadrupole moment can take positive or negative values, which refers to prolate, or oblate charge distribution respectively, the unit of this parameter is barn ($10^{-28}m^2$), and related with reduced quadrupole transition probability B (E2) by this relation: [12] [13]

$$Q_0=\left[\left(\frac{16\,\pi}{5}\right)\frac{B(E2)\uparrow}{e^2}\right]^{1/2} \quad (9)$$

3. Results and Discussion

The study of the relationship of nuclear decay modes (alpha and beta) emission with the deformed shape of nucleus have been done by calculating the deformation parameter (β_2) (deviation from spherical shape) and eccentricity (e) (represented the radioactivity) for even-even nuclei in uranium-238 and thorium -232 series.

The deformation parameter (β_2) related with reduced quadrupole transition probability B (E2) and average radius nuclear R_o^2 calculating by using equation (1).

The results of deformation parameter (β_2) was plotted as a function to the nuclides of each series to shows the effected of nuclear decay modes (alpha and beta) emission on the degree of the deformation of nuclide (shape of nuclide) as shown in bar chart in figure (1).

We can note from this figure that the value of deformation parameter for nuclides decay by beta particles emission (red bar) is lower than the deformation parameter values for nuclides which decay by alpha particles emission (blue bar). i.e., the decrease in the deformation of the shape of nuclei (approach in there shapes to spherical shape) which decay by emission of beta particles is greater than the decrease in the deformation of the nuclei which decay by alpha particles emission for two series.

The eccentricity (e) which denotes to the radioactivity can be calculating depending on the minor (a) and major (b) ellipsoid axis.

The results of eccentricity (e) are plotted as a function to nuclides of two series to shows the effected of eccentricity (e) (how much the conic section deviates from being spherical) by radioactive decay modes (alpha and beta) emission as shown in figure (2).

From this figure, it can be observed that the values of the eccentricity (e) of the nuclei that decay by emission beta particle (red bar) are lower than the nuclei that decay by alpha particle emission (blue bar).

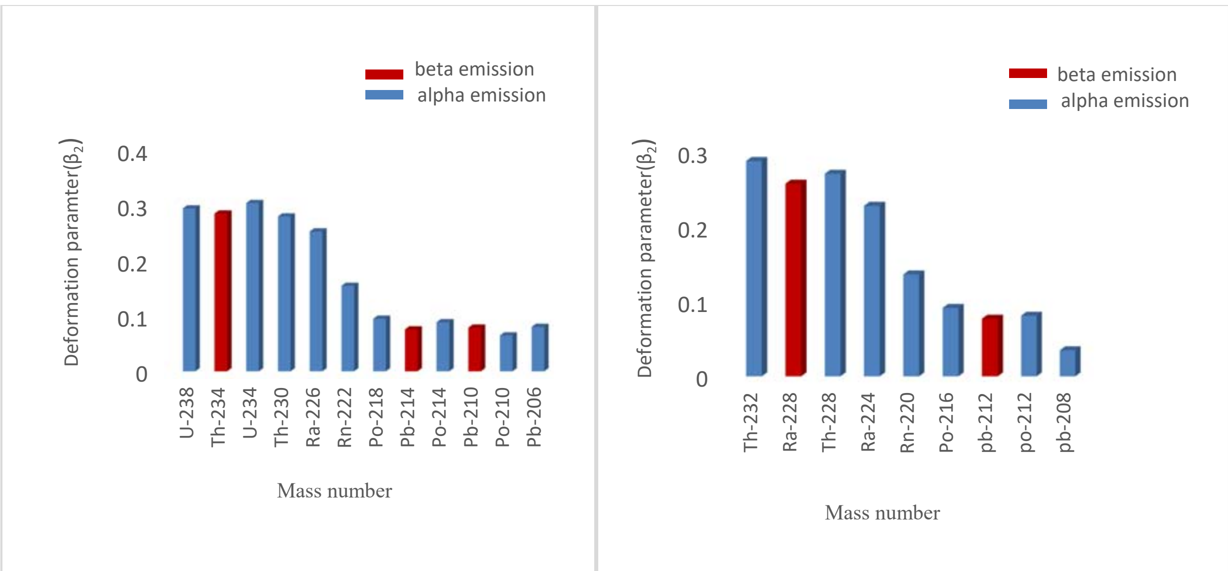
That's mean the decay of nuclei by beta emission lead to the stability of nuclei faster than alpha emission in the radioactivity process.

From figures (1&2), we can note clearly that the effected of the decay modes on the deformation parameter (shape of nuclides) is greater than eccentricity (the radioactivity).

Finally, the relationship between the deformation parameter (β_2) and eccentricity (e) studied by plotting deformation parameter as a function to eccentricity (e) for two series as shown in figure (3). From this figure, it is very clearly that the relationship between them is an exponential curve, also an empirical equation extracted from this curve.

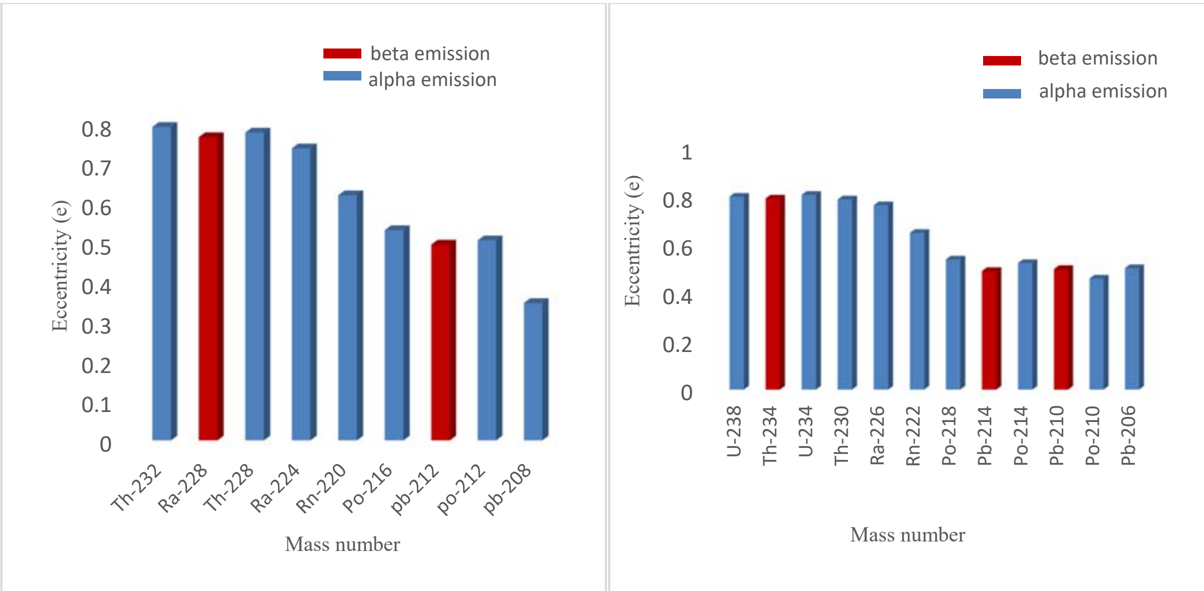
This empirical equation have been used to calculate the deformation parameter for even-even nuclide in uranium-238 and thorium -232 series, the results of deformation parameter which produce from empirical equation are with a good agreement to the values that calculated from equation (1) as shown in figure(3).

In addition, this empirical equation can applied to calculate the deformation parameter (β_2) for even-even nuclei, which have eccentricity (e) value.



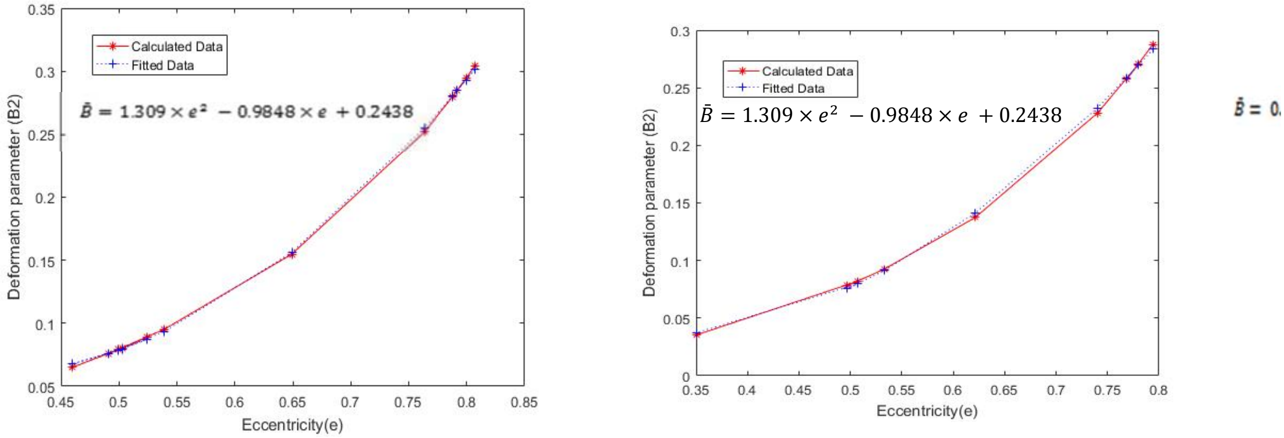
(a) (b)

Fig. 1 Bar chart of the deformation parameter (β_2) with decay mode of nuclei for: (a) ^{238}U series (b) ^{232}Th series.



(a) (b)

Fig. 2 Bar chart of the eccentricity with decay of nuclei for: (a) ^{238}U series (b) ^{232}Th series.



(a) (b)

Fig. 3 The relationship between deformation parameter (β_2) and Eccentricity (e) of nuclei for: (a) ^{238}U series (b) ^{232}Th series.

4. Conclusions

The results of this work show that the value of deformation parameter (β_2) as well as the eccentricity (e) of nuclei, which decay by emission of beta particles, is lower than the values of these parameters of nuclei decay by emission of alpha particles for two series.

The effected of the decay moods alpha and beta on the deformation parameter is greater than the effected on the eccentricity.

The relationship between the deformation parameter (β_2) and eccentricity (e) is an exponaliol relation.

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