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A Crucial effect of $Q_\alpha -$ Value and pre-formation factor on the alpha decay half- lives for heavy nuclei :systematic study

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THE most important factors in -decay are the Alpha particle preformation factors P_α and the Qα -value, which provide more information about nuclear structure. The $P_\alpha -$ value, which was retrieved from the cluster formation model (CFM), was carefully explored, whereas the Qα -value was identified (firas),(F.H1), (F.H2) and (Buck and Merchant) respectively. It turns out that the alpha decay energy has a significant effect on the accuracy of determining the half-lives of heavy nuclei. Since any change in the alpha decay energy, no matter how small, will have a very clear effect on the half-life of any nucleus .The Royer and Brown formulas were used to compute the theoretical alpha decay half-lives. The findings suggest that the P_α and Qα -decay energies are crucial observable values for conveying information about nuclear shell structure. In addition, P_α and Qα have a good friendship. This suggests that the P_α could support the Gieger–Nuttalrelationship.particularly in the discovery of new non-existent nuclei.

Keywords: Alpha decay energy, Cluster formation model, Half-life, Preforming factor, Super heavy nuclei.

Introduction

Nuclear physicists can investigate issues like magic numbers and the island of stability using super heavy elements. These are useful in understanding the characteristics of nuclear structure in the ultra-heavy region. Experiments on Super Heavy Nuclei have recently been conducted super heavy nuclei (SHN) , On the other hand, because -decay is the primary decay mode of SHN, it is essential for the observation of -decay from an unknown parent nucleus to a known daughter nucleus to find new components. The experimentalists, on the other hand, require the half-life value in order to design their experiments. Furthermore, measurements of the decay provide trustworthy information on the nuclear structure, such as ground state energies, half-lives, nuclear spin and parities, shell effect, nuclear deformation, and shape coexistence [1-4].

The Qα -value is an important consideration when calculating the α-decay half-life. Where the half-life is very sensibility to Qα-values, with an unpredictability 1 MeV in (Qα) corresponding to an uncertainty of α-decay half-life ranging from 103 to 105 times for the heavy elements area [5] . The nuclei are not comprised of condensed matter, All nucleons have the same nuclear force, which is charge independent, and the nuclear force saturates, according to this concept. The Liquid- drop modelLDM was successful in describing several nuclear characteristics, including the renowned nuclear binding energy formula, based on this assumption. Nonetheless, this concept does not explain the nucleus' magic numbers. With the current approach, calculating the Q_α-value of -decay that is nearly equivalent to the kinetic energy of the released -particle is challenging. It may thus be beneficial to extract a Q_α-value expression from the LDM,It can be used to calculate the half-lives of unidentified nuclei quantitatively [6] to demonstrate their influence on the value of alpha energy decay,

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they used the Q_α-value to obtain a closed-form formula for the decay half-life. The even-even 228-232Th isotopes' nuclear structural characteristics are investigated empirically [7] based on a nuclear phenomenology perspective Manjunatha and Sowmya (2018) investigated the spontaneous, ternary, energy, and cluster decay of SHN Z = 124 predicted isotopes [8].

For super heavy elements (Hs, Ds, and Cn) having even-even atomic numbers numbers Z = 108, 110, and 112, estimates of formation energy, Qα-value, and surface energy, which are dependent on variations in binding energies, are important for obtaining Preformation probability estimates that are realistic [9]. A study has been conducted with the goal of proposing the processes modifying the probability as a new formula for determining the Q_α-Value of heavy and super-heavy nuclei with great accuracy between Z=78 to 120 (e-e and e-o nuclei) in order to forecast the half-lives of all nuclei under study, particularly at the super heavy nuclei [10]. This prompted the same thing researcher to conduct more in-depth studies of alpha decay energy, including modifying the LDM to estimate the Qα-values of heavy and SHN nuclei with Z = 78 to 120 (e-e and e-o nuclei), as well as introducing the theoretical quantity, which describes the Qα-value dependence of mass number (A) to predict the Qα-value of SHN. Finally, it investigates the relationship between separation energy differential (Sp–Sn) and mass number, as well as adjusting the quark model to compute the (Qα -value) in order to suit the empirical data with good precision. As a new, including a better version as well as a generic version. This can be accomplished once the number of neutrons and protons has been determined, regardless of the mass of heavy and super heavy nuclei, which ranges from Z = 78 to 118. (A) nuclei (odd and even)[11-13].

Various descriptive and microscopically theoretical methods have been employed to investigate -decay employing Viola-Seaborg for example (VSS) [14], the cluster model [15] ,GLDM [16] and density-dependent M3Y (DDM3Y) effective interaction [17]. Through a recent study conducted by us, the concept of the effect of angular momentum alpha decay was introduced using the relative excess of neutrons((N-Z)/A) A additional set of parameters has been included to our formula were found by the least square fit method for alpha decay for 128 nuclei [18,19]. In 1998, Loaves and colleagues discussed the microscopic hypothesis of alpha cluster radioactivity decay. The quantum mechanical preformation probability for a two-cluster component in the parent nucleus' constrained initial state [20]. It describes the effects of the parent's various nuclear structure features, such as their isospin asymmetry of the even-even nuclei [21].

In addition, numerous theoretical and practical attempts to calculate the preformation factor P□ have been performed [22,23].

The goal of this research is to look into a collection of theoretical formulae that can be utilized to determine nuclei's alpha decay energy for nuclei (Qα). This is done in order to get the most precise formulas in terms of approach and conformity to practical decay energy values(Qα-value). The two formulae[Brown ,Royer] will also be used to calculate the half-lives of the alpha decay energy . This is to see how the decay energy affects the half-lives, which may be used to look into unknown nuclei and discover their structural properties like magic numbers and the island of stability. The pre-formation coefficient (P_α)of alpha particles at the moment of their decay from the parent nuclei was calculated using the alpha particle cluster formation model (CFM). This study aims to predict the improvement role of Q_α –values with different formula on the accurate values of half –lives for heavy nuclei .And the possibility of preformation alpha P_α to confirm the Geiger-Nuttal relation.

Theoretical framework

Various formulas will be applied to theoretically determine the alpha decay energy Q_α –value and compare the extracted findings with the practical values to establish the optimum method for achieving the best convergence between theoretical and practical alpha decay energy values.

Dong et al. formula

Based of liquid drop model (LDM), Dong et al. was proposed a formula for the Q_α - value of super heavy nuclei (SHN) as following [24] Theorem Q_α has been calculated utilizing the equation,

$$Q_\alpha = aZA^{-4/3}(3A - Z) + b\left(\frac{N-Z}{A}\right)^2 + c\left[\frac{|N-152|}{N} - \frac{|N-154|}{N-2}\right] + d\left[\frac{|Z-110|}{Z} - \frac{|Z-112|}{Z-2}\right] + e \quad \ldots\ldots (1)$$

where N, Z and A are the proton, neutron and mass number of parent nuclei , respectively .

a = 0.9373 MeV, b = –99.3027 MeV,
c = 16.0363 MeV, d = –21.5983 MeV
and e = –27.4530 MeV.

Firas formula

In this formula is to set with the Quark –like model To fit the practical results with sufficient accuracy, a model to determine the (Q_α–value) was developed. As a brand new, created version, and as a generic version. Independent of the mass of heavy and super heavy nuclei, this is accomplished once the number of neutrons and protons is known As shows in Equation (2) [12].

$$Q\alpha = \left[3A - \left(\frac{N^2 - Z^2 - 4N + 4Z}{Z-2} + 21\right)\right] * 2.65584 - \left[3A - \left(\frac{N^2 - Z^2}{Z} + 9\right)\right] * \square.63043 + C \quad \ldots \quad (2)$$

where Z, N and A are the number of proton, neutron and mass number of parent nuclei

$C = 25.7\square$ MeV

Firas and Hala (F.H1) Formula

Firas and Hala were proposed a new formula for the alpha decay energy by combining the idea of the path ways modulation probability for the alpha particle with the employment of nuclear liquid Drop Model for super heavy nuclei represented by the following formula (11).

$$Q_\alpha = aZA^{-\frac{4}{3}}(3A - Z) + b\left(\frac{N-Z}{A}\right)^2 + e + c\left[\frac{(N-Z)-(Z-2)}{A-4} - \frac{N-Z}{A}\right] \ldots\ldots\ldots (3)$$

When this formula (1) (i.e. the generalized Liquid Drop Model) is used to figure out Q_α-value, the outcomes are poor, with large differences between the theory and the practical Q_α-values and a standard deviation of 1. (0.7798). Based on eq, it could be possible to derive a more precise equation for Q_α-value with less parameters (1). Obtaining a different form of nuclear-bi $\frac{N-Z}{A}$ energy, the term of relative neutron excess (was included to Eq.(2), and when this formula is substituted in Eq.(11), the following form is obtained.

N, Z and A are the number of neutron and proton andmass number of parent nuclei .

a=0.9373 MeV,
b=-99.3027 MeV,
e =-27.453

c=

$$\begin{cases} 450 \; for\ nuclei \;\; 78 \leq Z \leq 90 \\ 170.65 \; foe\ nuclei \; 92 \leq Z \leq 120 \end{cases}$$

Firas & Hala (F.H2) Formula

Firas and Hala were modified the (LDM) to predict the $Q_\alpha - value$ of heavy and super heavy nuclei .This formula is represented by the following Equation[11].

$$Q_\alpha = aA^{-1/3} + bZA^{-1/3}\left(1 - \frac{Z}{3A}\right) - c\left[1 - \frac{2Z}{A}\right]^2 \ -35 \quad \text{................(4)}$$

where Z and A are the number of proton and mass numbers of parent nuclei.

a = 44.8 MeV

b = 2.856 MeV

c = 92.8 MeV

Buck and Mrechant Formula

Buck and Merchant were employed a square –well nuclear potential phase a surface –charge coulomb potential ,to satisfactorily describe $Q_\alpha - value$ s ,that represented by the following formula (25).

$$Q_\alpha = \left[\frac{A_p}{A_p - 4}\right]E_\alpha + \left(0.63Z_p^{7/5} - 80Z_p^{2/5}\right) * 10^{-6}MeV \quad \text{.......(5)}$$

Where Z_P = proton number, A_P = mass number of the $\alpha -$ decay,. E_α is the kinetic energy of alpha particle of every parent nucleus.

By applying Equations (1,2,3 ,4 and 5) to the included in our current study, which extends between $78 \leq Z \leq 126$ for all types nuclei (e-e, e-o , o-e , and o-o)

Half –Lives Calculation

One of the purpose of this research is the portend the half- life heavy and super heavy nuclei To achieve that can be adopted by Brown's and Royer formulas. As these formulas depend on the alpha decay energy ($Q_\alpha - value$), then the theoretically calculated energies were used as specified in paragraphs (2.1), (2.2), (2.3), (2.4), and (2.5) and once with the practical values of the decay energies. Thus, it will be clear a significant impact of ($Q_\alpha - value$) values on determining the half-life of the studied nuclei, as well as which of the two formulas has an advantage in the practical half-life approach.

Brown's formula

derived from the semi-classical Wentzel-Kramers- Brillouin (WKB) approximation and fit to experimental data [26].

$$\log T = 9.54\frac{(Z-2)^{0.6}}{\sqrt{Q_\alpha}} - 51.37 \quad \text{... ... . (6)}$$

Developed formula by Royer

The is one of the most salient formula for determining the Half-lives of alpha decay and given by Royer [27]:

$$logT_{sec} = a + bA^{1/6}Z^{1/2} + \frac{CZ}{\sqrt{Q_\alpha}} \quad \text{... ... . . (7)}$$

where A= mass number and Z = charge number of the parent nuclei. a, b, and c are constants.

hlog =

a = –25.31 b = –1.1629 c = 1.5864 for Z = even, N = even,

a = –26.65 b = –1.0859 c = 1.5848 for Z = even, N = odd,

a = –25.68 b = –1.1423 c = 1.5920 for Z = odd, N = even,

a = –29.48 b = –1.1130 c = 1.6971 for Z = odd, N = odd.

Alpha-Preformation Factor (P_α):

The Cluster Formation Model (CFM) [28] is a well-known method for calculating P_α. The formation energy and total energy are used to determine the P_α.

$$\mathbf{P_\alpha = \frac{E_{f\alpha}}{E}} \quad \text{... ... ... (8)}$$

where $E_{f\alpha}$ signifies the energy of cluster formation.

E stands for total energy. This combines the intrinsic energy of the alpha cluster with the interaction energy between the remaining nucleus and the alpha cluster Separation energy can be utilized to obtain formation energy in the following way:

$$E_{f\alpha} = \begin{cases} 2S_p + 2S_n - S_c(even - even) \\ 2S_p + S_{2n} - S_c(even - odd) \\ S_{2p} + 2S_n - S_c(odd - even) \\ S_{2p} + S_{2n} - S_c(odd - odd) \end{cases} \quad \text{... ... ... (9)}$$

$$E_{\square} = S_c(A,Z) \text{... ...} (10)$$

where S_{2P} and S_{2n} are the two-proton and two- neutron separation energy which can be determined by binding energies [29; 30].

S_{2p} (A, Z) = B(A, Z) – B(A – 2, Z – 2)… (11)

S_{2n} (A, Z) = B(A, Z) – B(A – 2, Z)….....(12)

where The alpha cluster separation (S_c) stands for -cluster separation and is determined as follows:

$$S_c\ (A, Z) = B(A, Z) - B(A - 4, Z - 2) \ldots (13)$$

Thestandard deviation (σ) are calculated as follows:

The statistical equation for standard deviation (σ) was used to evaluate the theoretically calculated half-lives and decay energy. In order to compare these values with the practical data [19,31] using the following two equations:

$$\sigma = \sum_{i=1}^{N} \left| Log_{10} T_{\frac{1}{2}}^{exp} - Log_{10} T_{\frac{1}{2}}^{cal} \right| / N \ldots\ldots\ldots (14)$$

$$\sigma = \sum_{i=1}^{N} |Q_\alpha exp. - Q_\alpha cal.| / N \ldots\ldots\ldots\ldots (15)$$

Results and Discussion

In order to reveal the important effect of P_α values on the alpha decay energy properties, can adjust the Cluster Formation Model (CFM) to assess the P_α for all type nuclei. Using the binding energy ofparent and daughter nuclei. In addition to the separation energies of the last two protons and two neutrons of the above nuclei. Figure 1 reveals the relationship between P_α, theoretical Q_α *value* as a function of the number of neutron (N) for all type nuclei of the best fit formula (Eq. 5) obtained from formula (Buck) as in (Eq.5), because I has the least standard deviation of half- lives (Royer…et) which has remarkable convergence with practical values of half-lives.

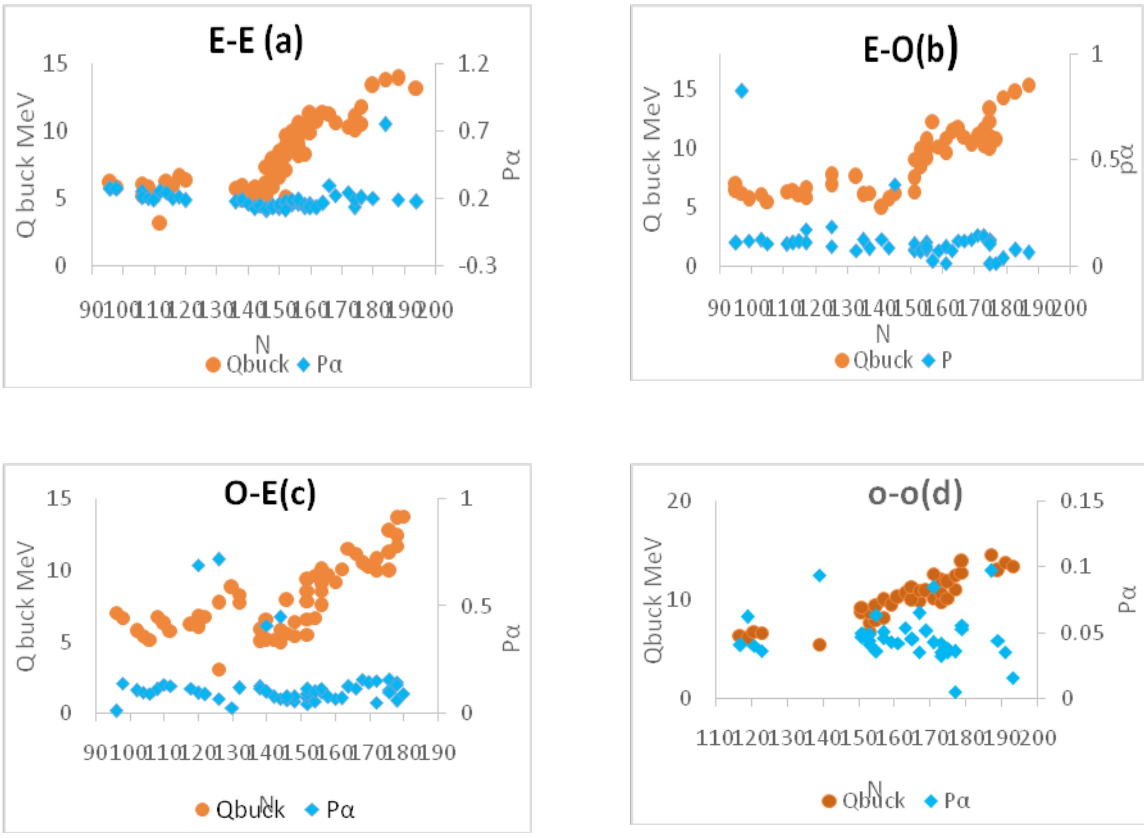

Fig. 1. (a ,b ,c ,d) The $Q\alpha$ and $P\alpha$ Versus neutron number (N) for (e-e), (e-o), (o-e) , and (o-o) nuclei of according to (eq. 5).

Eq.(8) calculates alpha particle preformation which decreases as the number of particles increases (N). The number of closed shell nuclei increases rapidly at N=126 and N=184 (magic number).(Zhang et al.; Zhang et al.; Zhang et al.; Ahmed et al., [32-35] found a comparable drop in alpha clustering in open – shell nuclei as they progressed to closed shell. There have been numerous confirmations that shell effects play a key role in alpha preformation and that heavy nuclei with magic shell have the lowest Pα values [34-38].

This behavior has also been described in [32] for a wide variety N=126 closed shell until the next neutron shell is near. When discussing the behavior of alpha decay energy as (N) increases, one can see the $Q_\alpha -$ value rise as (N) rises throughout the board As seen in Fig. 2. Before N=123, the calculation decay energies for even –even nuclei increase slowly, but when (N) increases,. The same behavior appears when (Z=82, A=188) nucleus. Q_α decreases when the (N) number approaches the (N =126) closed shell, until it reaches the next neutron closed shell. To put it another way, the values of Pα and Q_α_ have a significant impact on the nuclear structure.

Even –even super heavy nuclei, as well as $^{20-314}116$ [37]. Pα quickly drops after Fig. 2 depicts the half-life of each Brown (Eq. 6) and Royer (eq. 7) relationship with the mass number (A) once when substituting the value of the alpha decay to the formula buck and merchant , which shows the least deviation Standardized according to Tables 1 and 2. This is to demonstrate the impact of various decay energies on the half-lifeenergy according to the formula F.H2 equation (4) and again at (Eq. 5) according various decay energies on the half-life

The comparison of our results with Brown formula (Eq. 6) and Royer formula (Eq. 7) Alpha decay half lifetimes is shown in Fig. 2. Two formulas provide numbers that are clearly different. This is due to the fact that the Q_α values we used are significantly different.

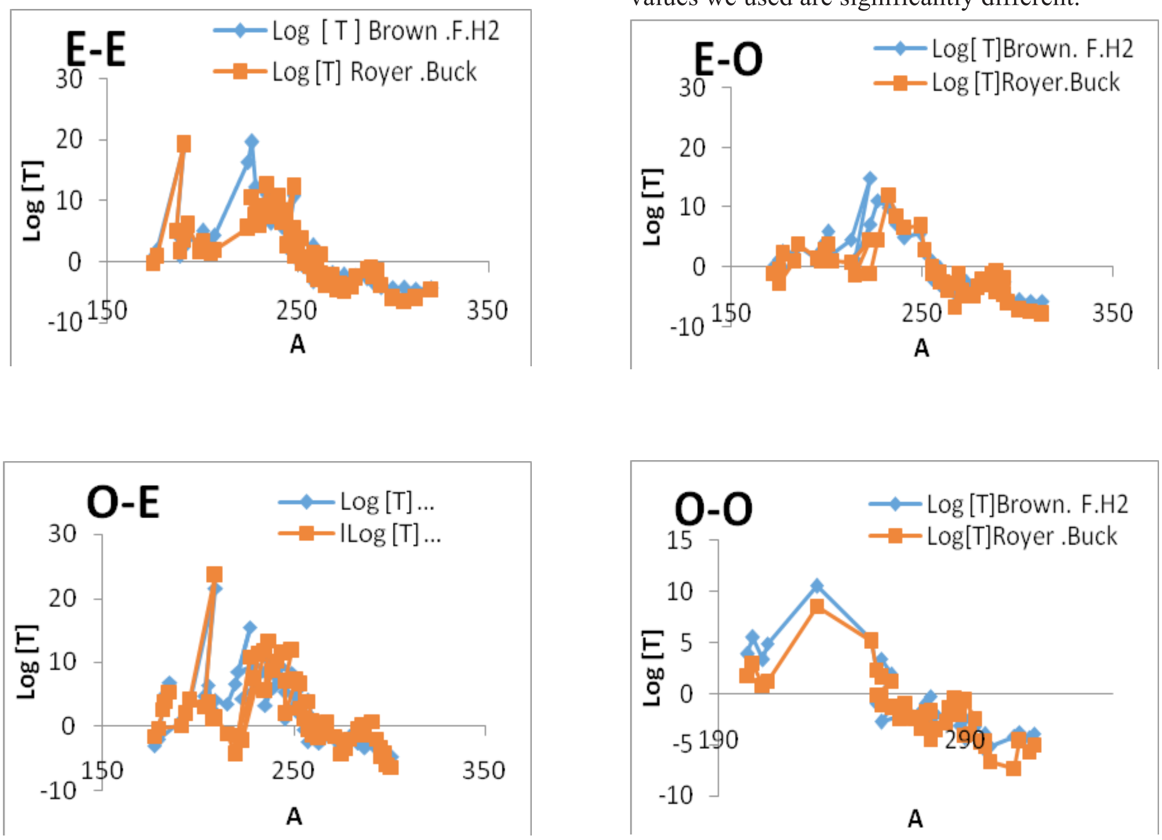

Fig. 2. Relationship of $Log\left[T_{\frac{1}{2}}\right]$**. Brown. F.H2, . Royer. Buck, and mass number (A). for e-e , e-o , o-e, and o-o nuclei.**

We notice from Fig. 2 (E-E) that the half-life is the highest possible at the magic number (Z=82, A=190) due to the large nuclear binding energy as it belongs to a closed shell for the number of its protons and lower decay energy and for both formulas. Note that this behaviour is repeated for the rest of the types of nuclei with magic numbers. When entering different values of the decay energy (Q_α) dependent on different formulas as proven in Tables 1 and 2, the effective effect of them on the half-life is shown in terms of balancing it with the practical values.

Figure 3 shows the relationship of the half-life according to the formula (Log[T]Royer. Buck) with the best theoretical values for the alpha decay energy according to the formula (Buck). confirming the possibility of their adoption in determining the alpha decay energy, especially the formula (Buck).

The is clear from the above figure that this behaviour is consistent with the Gieger- Nuttal law, as the relationship is inverse, except for nuclei that have magic numbers or numbers close to magic numbers.

Table 1 shows the standard deviation values (σ) of the alpha decay energy when compared with the practical data, as it becomes clear that the formulas (Firas) and (Buck) (Eq. 2 , 5) showed the least standard deviation (0.18 and 0.136).

While Table 2 shows the amount of the standard deviation (σ) between the theoretical values of the logarithm of the half-lives of formulas Royer and Brwon (Eq. 6 ,7) with practical data. As it becomes clear that the least standard deviation ($\sigma = 0.32$) of Royer's formula was when $Q_{\alpha-}value$ was substituted for values according to the equation Buck. While the formula Brown showed the least standard deviation ($\sigma = 0.3$) according to equation (F.H2) (Eq. 4).

One can see through Table 2 the extent of the extreme importance and the Having an impact of the values of $Q_{\alpha-}value$ on the approach of the half-life of the nuclei to their practical values.

It has an effective effect. For example, the nucleus ($^{186}_{80}Hg_{106}$) when calculating the logarithm of the half-life according to the decay energy of the process alpha was estimated (5.158), while the value of (5.32) was expressed according to $Q_{\alpha-Vlue\,Buck}$

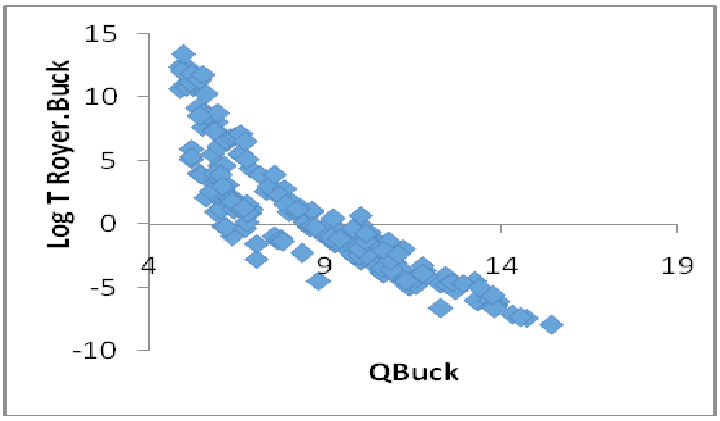

Fig. 3. The predicate of] Royer Buck with Q_α Q_α –values according (Buck formula) for e-e, e-o ,o-e, and o-o nuclei .

TABLE 1. shows the values of the standard deviation (σ σ) of the alpha decay energy for all the used formulas

σ	formulas
1.66	F.H1 (eq.3)
0.21	F.H2 (eq.4)
0.916	Dong (eq.1)
0.18	Firas (eq.2)
0.136	Buck (eq.5)

TABLE 2. shows the values of the half-life standard deviation (σ σ) of alpha decay according to the formulas (Brown) and (Royer) for all the used formulas .

σ	Formulas Brown	σ	Formula Royer
1.089	Brown –exp.	0.32	Royer-exp.
3.21	F.H1	5.91	F.H1
0.3	F.H2	0.48	F.H2
3.05	Dong	4.02	Dong
1.3	Firas	0.45	Firas
1.08	Buck	0.32	Buck

As we note that a small change in the decay energy will lead to a noticeable change in the half-life

Table 2 shows the values of the half-life standard deviation (σ) of alpha decay according to the formulas (Brown) and (Royer) for all the used formulas .

Conclusion

The results showed that (P_α) has a major role in the possibility of forming alpha particles at the moment of dissolution, especially at closed crusts, whether in the number of protons and neutrons or both. It turns out that the alpha decay energy has a significant effect on the accuracy of determining the half-lives of heavy nuclei. Since any change in the alpha decay energy, no matter how small, will have a very clear effect on the half-life of any nucleus. The formula (Buck) gave the alpha decay energy a little standard deviation compared to other formulas, so it can be relied upon in describing the half-life of the studied nuclei. The formula (Royer) showed its high accuracy in determining the half-lives according to the formula (Buck) for the decay energy.

The alpha particle reshaping agent (P_α) can achieve the Gieger-Nuthal formula, particularly in the discovery of new non-existent nuclei.

Authors' declaration:
- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are mine ours.

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