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Calculating the Radii of the Even-Even Nickel Isotopes

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Abstract

The current investigation concentrated on even-even nuclei forms to isotopes that have masses number less than 100 (A>100) to $(^{58-68}_{28}Ni$)elements . This includes a look at deformation parameters (β_2) derived from reduced electric transition probability $(E2)\uparrow$ as well as distortions parameters(δ) derived by intrinsic electric quadrupole moment(Q_0). A Roots mean square Radius$< r^2 >^{1/2}$ We studied the most important deformation parameters (δ,β_2) , and major and minor of ellipsoid axes (a,b) in addition to the difference between these axes (ΔR) All these parameters were calculated using the deformed shell model equations and applied theoretically in a special program. Differences in nuclei forms were observed for selected isotopes via drawing two 2- dimensional shapes. According to the current findings. Thus the distortion coefficients decrease as the number of neutrons approaches the magic number**.** Thus it was observed that the most distorted and inclined isotopes of the elliptical shape are the isotopes with numbers of protons and neutrons far from the magic numbers Also, the obtained results were compared with the theoretical results from Raman source by "single-shell Asymptotic Nilsson Model "(SSANM), and noticed that was little change in the results. Also observed from the results that $(^{58}_{28}Ni)$ is the most stable isotope and has a clear spherical shape because (Z) is equal to (28) a magic number and (N) is equal to (30) a number close to the magic number.

Keywords: A deformation parameters(β_2, δ) , An electric quadruple moment Q_o , A probability of the transition $B(E_2:0^+\rightarrow 2^+)$, A Roots mean square Radius$< r^2 >^{1/2}$.

Introduction

The protons and neutrons that make up the shell structure of the atomic nucleus are mirrored by the shape of the nucleus [1]. If the shells are filled, we are talking about a "magic" nucleus, which is spherical in shape [2]. However, most cores tend to be that deformed because their shells are only partially filled. The most common shapes encountered are oblate (flat, pancake and pillow) or prolate (elongated, cigar- and rugby-ball-shaped) [3]. In some cases, rearranging the neutrons or protons within the nucleus itself is enough to change a shape, so a nucleus can take Various shapes depending on different energies [4]. If the energy between these states is close, the other shapes can combine [5]. Depending on the relative pivot values of the ellipsoid shapes, it can subdivide deformed nuclei into oblate, prolate, and triaxial deformed nuclei. It can be observed that there are different shapes of

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nuclei in the ground state and only a few have a spherical shape, predominating in the same nucleus 5.The arrangement of valence nucleons in an empty shell is what causes the nuclear deformation, hence a deformation, only happens whenever both the proton (p) & neutron (n) shells are half filled [6]. Quadruple deformations parameter which is degree of nucleus shape difference from the sphere, as shown in Fig. 1 [7].

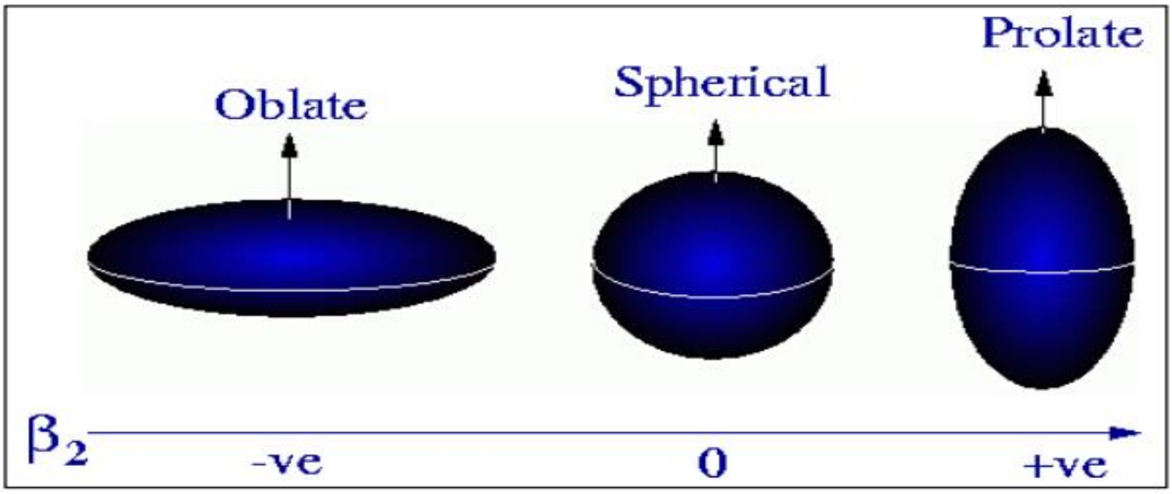

Figure .1. Diagram showing oblate, spherical and prolate shapes. The arrows for the oblate and prolate shapes indicate the symmetry [7].

The main objective of the study is to calculate the radii of even-even nickel isotopes by using the special deformation equation and applying it theoretically in matlab programs, and through it also calculate the deformation coefficients, through which the shape of the nuclei was determined.

Deformation parameter:

According to the liquid-drop model, nuclei may be pliable and soft, this indicates that the shape of the nucleus may differ significantly from the spherical shape. The researchers found a large number of nuclei in regions with neutron number (N) and proton number (P) away from the magic values that have a noticeably distorted charge distribution [7].

The assumption of independent nucleon motion in an average potential well serves as the theoretical underpinning of the chance model. the specific nucleon's interactions with every, other nucleon in nucleus are represented by this potential well [8].

The transition probability B(E2) is used to calculate the deformation parameter β_2 for the $2^{+} \rightarrow 0^{+}$ transition. In the second (2^{+}) and first excited states 0^{+}, there is an alternative to quadratic analysis. Basic nuclear information that supplements our understanding of nuclide level energies [8, 9]. The $(E2)$ $\uparrow$values, in general, Confirmation of the large range, of quaternary, distortion in nuclides, estimated using the Global Beast Fit equation:

$$B\ (E2)\uparrow = 2.6\ E\gamma^{-1} Z^{2} A^{,-2/3} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

, Where: Z is the atomic number,

A is the mass number of a nucleus, and

$E\gamma_0$ energy of gamma ray transitions in units of KeV.

This indicates, that (E2) values in that equation are fundamental on experimentally-measured amounts ($E\gamma$, Z, A) instead of relying on nuclear models [10]. The parameter of the deformation β2 is an effective, model that depends on quantum mechanics and is simple to visualize[10]. Assuming this potential well describes the interactions of a particular nucleon with all other nucleons in the nucleus [10]:

$$\beta_2 = ,4\pi\ /\ 3ZR_o^{\ 2}\ [B\ (E2)\uparrow e^{2}\ b^{2} / \ e^{2}]^{1/2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where: Ro: is the nuclear average radius, which is derived from the equation:

$$R_o^{\ 2} = 0.0144\ A^{2/3}\ barn \qquad \ldots\ldots\ldots\ldots\ldots\ldots..\ 3$$

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The deformation parameter δ is calculated using intrinsic quadrilateral electrical moments Q_O, which is used as it provides important information about shape and deformation because it measures the deviation of the charge distribution from spherical symmetry [11] .

$\delta = 0.75Q_o / (< r^2 > Z)$ …………………….. 4

, Through the following equations, the mean radius $< r^2 >$: can be calculated

$< r^2 > = 0.63R_o^2 (1+10/3(\pi a_o/R_o)^2)/(1+(\pi a_o/R_o)^2)$ $(A \leq 100)$. ………. 5

$< r^2 > = 0.63(1.2A^{1/3})^2$ $(A>100)$ …………….6

Where: R_o: The radii potential parameters are $R_o=1.07 A^{1/3}$ fm and, ao=0.55(fm), and ao is derived from the information on fast electron scattering. An self-quadruple moment, Equation-based calculation via [9] :

$Q_o = [(16 \pi /5) B(E2) e^2 b^2 / e^2]^{1/2}$ ………………7

Nuclear Shape

When nuclei are stable their shape is generally spherical. The goal of this effort reduces the energy of surface. As a result, little spherical sections are noticed such as in the region 150<A< 190 and only the ratio can be utilized to define these irregularities [12]:

$\delta = \Delta R / R$ ……………….8

, Where:

ΔR denotes the variance between the semi-, minor and semi-, major axis

R is an average of the nuclear radius.

$\Delta R = (b - a)$ ……………….9

Where:

a, b: major and minor of ellipsoid axes.

radius of the root mean square charge (isotope transformation):

(rms) is the radius of the nuclear charge $R = \langle r^2 \rangle^{(1/2)}$, together with other nuclear ground state properties, and is considered one of the keys to information about the main nuclear materials that indicate the effectiveness of the nuclear structure, for example: closure crust and start to deform [13].

, Direct inference of the root square radius (rms), $\langle r^2 \rangle^{(1/2)}$, is made from the scattering electron distribution; The radius of charge distribution for an evenly charged sphere is squared [14,15]:

$$\langle r^2 \rangle = \frac{3}{5} R^2 = \frac{3}{5} R_0^2 A^{2/3} \quad > 100 \quad \ldots\ldots\ldots\ldots .10$$

Where:

A: number mass

R: spheres radius.

, $= R_0 A^{1/3}$

A probability of reduced electric quadrupole transition (E2) ↑

The best way to create a nuclear structure and to test models of nuclear structures is through radiated electromagnetic transitions between nuclear states [16]. The magnitude of the critical electric quadruple moments the energy of the lower nucleation levels the average periods of nucleation states and the nuclear distortion coefficient β depend on B (E_2), transition. The collective effects, that multiple, nucleons can be involved in are referred to as large quadruple moments and vector forces [13] . Determines the transition probability of the lower electric quadriupole B(E_2) of ground spin state for a first excite spin 2^+ state [17]:

$(E_2 : 0^+ \rightarrow 2^+) = 5/16\pi\, e^2 Q_0^2$ …………………..11

, where:

$(E2)\uparrow$: Reduced chance of an electric quadruple transition in unit of $(e^2 b^2)$.

Q_0: the intrinsic quadruple mountain in barn (b) units.

If Q_0 Calculate elliptically charged and homogenously charged with Z charge and (b) and (a). by sign (b) relative to x-axis's, Q_0 may be[18]

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$$Q_0 = \frac{2Z}{5}(a^2 - b^2) \quad \ldots\ldots\ldots\ldots..12$$

Eq 9, can be used to calculate the average, radius: R = ,1/2 (a + b) and ΔR = (b- a), with = ,ΔR/R, by Eq. 9, the quadruple moments is given if the deviation from sphericity is not very significant [19]:

$$Q_0 = \frac{4}{5} ZR^2 \delta \quad \ldots\ldots\ldots..13$$

A, values of Q_0 are, determined via the equation.

$$\delta = 0.75Q_o / (< r^2 > Z) \quad \ldots\ldots\ldots\ldots14$$

The two following equations yield the semi-axes (a) and (b) [20].

$$a = \sqrt{< r^2 > (1.66 - \frac{2\delta}{0.9})} \quad \ldots\ldots\ldots..14$$

$$b = \sqrt{5 < r^2 > -2a^2} \quad \ldots\ldots\ldots 15$$

Results and Discussion

Several characteristics for elemental nickel (Ni) and its isotopes, ^{58}Ni, ^{60}Ni, ^{62}Ni, ^{64}Ni, and 68Ni required, have been estimated in the current study for double nuclei with masses and numbers fewer than 100 (A > 100). The following criteria must be met for this research:

From table 1, we observe that the lowest value of the deformation Parameter (β_2) is for the ($^{68}_{28}$**Ni**) equal to (β2 = 0.1530)and the largest value of deformation parameters for ($^{62}_{28}$**Ni**) (β2 = 0.2209). The remaining values of β_2 is, ranging, between, these (2 values). We also note that the lowest value of the deformation Parameter (δ) for the ($^{68}_{28}$**Ni**) is equal to (δ = 0.1100) and the largest value of deformation parameters for ($^{62}_{28}$**Ni**) (δ = 0.1568). We also notice from table.1, that the values deformation Parameter (δ) of the elements increase with mass numbers (58, 60, and 62) and then begin to decrease with mass numbers (64, 66, and 68). It was also noted that the values of (Q_0) range from the highest value is (1.0561) to the lowest value is (0.7778) in table 1, All of these results are represented graphically in Figs. 2,3 and 4. Also, by using the results in table 1 , a relationship between the number of neutrons as a function to ($B(E_2)$) and(R_0^2), as shown in Fig. 5, 6 . Also, a ,relationship ,between (δ, β2) as a function of neutrons number was represented graphically as shown in the Fig. 7 This is because the nucleus of the ($^{50}_{28}$**Ni**) is one of the nuclei with double magic numbers (Z = 28, N = 50) , and therefore this nucleus is more stable than others as shown in the Fig. 8, .Also Fig. 7, shows the correlation between the neutron counts and the deformation parameters. Also, through the results shown in table 1, the relationship was drawn for low electrical transition potential (B (E2) Between the present work (P W) through the results above and the theoretical study obtained from the Raman source by "single-shell Asymptotic Nilsson Model "(**SSANM)** and it was observed from the drawing that there is agreement between the two axes and this is due to the convergence of the values obtained in the current work with the experimental values as show in Fig. 8.

In Table 2, we note that the highest value of transition potential T(s) is equal to 8.9416*10^6 at ^{66}Ni where and the lowest value of T(s) is 9.6248*10^{-13} at ^{58}Ni and the highest value of the average half-life is 1.0390*10^{12} at ^{58}Ni. The lowest value is 1.1184*10^{-7}at ^{66}Ni, and the highest value for the gamma energy is 2033at ^{68}Ni. Also, the gamma energy values shown in the above table were relied on to calculate the electrical transmission probability B(E2), and through (B(E2), it was calculated the deformation coefficients (β_2, δ) through which the shape of the nuclei was determined, depending on the deformation equation on which it was based on our current study.

Observing a root mean values the squared charge values of radius $\langle r^2 \rangle^{1/2}$ in the Table 3, We discovered that values rose as mass number A increased. It was discovered that computed values $\langle r^2 \rangle^{1/2}$ present work (P w) correspond well with the experimental value of $\langle r^2 \rangle$,$^{1/2}$ by the reference's for comparison purposes [21] .

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Table 1. the number of the mass for isotopes (A) Nickel, neutrons number (N), the energy of gamma to the first level E γ, average nuclear radius (R_0^2), low electrical transition potential (B (E2) ↑ in $e^2 b^2$ unit, moment Tetrapolar electrode (Q_o) in barn unit, and the parameters of the deformation (β_2, δ) to Ni.

				TheTheoretical Values		Present Work				
Z	A	N	E_γ (KeV)	(B(E₂) ↑ ($e^2 b^2$) for (SSANM)	$\beta_2$for (SSANM) (P.w)	δ	β_2	Q_o (b)	$B(E2)\uparrow$ (e^2b^2)	R_0^2
28	58	30	1454.28	0.016	0.0877	0.1491	0.2121	0.96320	0.0935	21.576
	60	32	1332.518	0.036	0.1286	0.1513	0.2142	1.0017	0.0998	22.069
	62	34	1172.9	0.054	0.1541	0.1568	0.2209	1.0561	0.1109	22.557
	64	36	1354.84	0.068	0.1693	0.1420	0.1991	0.9723	0.0940	23.04
	66	38	1424.8	0.079	0.1788	0.1348	0.1883	0.9384	0.0876	20.15561
	68	40	2033	0.084	0.1807	0.1100	0.1530	0.7778	0.0602	23.99

Table 2. A masses numbers (A), the neutrons numbers (N), a gamma energy of the ground level, the probability of the transition (T) and the average half-life (τ (s)) to Nickel (Ni) isotopes.

Z	A	N	E_i(kev)	E_γ(kev)	$t_{1/2}$ ʾ(s)	T (s)	τ (s)
28	58	30	1454	1454.28	(667 fs)$6.67*10^{-13}$	$9.6248*10^{-13}$	$1.0390*10^{12}$
	60	32	1332.501	1332.518	(0.713 ps)$7.13*10^{-13}$	$1.0289*10^{-12}$	$9.71995*10^{11}$
	62	34	1172.91	1172.9	(1.45ps) $1.45*10^{-12}$	$2.0924*10^{-12}$	$4.7793*10^{11}$
	64	36	1354.75	1354.84	(0.88ps)$8.8*10^{-13}$	$1.22698*10^{-12}$	$7.8750*10^{11}$
	66	38	1424.8	1424.8	(54.6h)$61.965*10^5$	$8.9416*10^6$	$1.1184*10^{-7}$
	68	40	2033	2033	(0.86 ms) 860	$1.241*10^3$	$8.0581*10^{-4}$

Taƅle 3 . numberʾs masse (A), the numbers of neutrons (N), a root meanʾs squares of the radius $< r^2 >^{1/2}$, the minor & major axies (b, a) additionally, what separates them (ΔR) in two ways for isotops of Nickel (Ni).

			A theoretical value	present work						
z	A	N	$\langle r^2\rangle^{,1/2}$ fm [21]	$\langle r^2\rangle$ fm	$\langle r^2\rangle^{1/2}$fm	a (Fm)	b (fm)	Δ R_1	Δ R_2	Δ R_3
28	58	30	3.7757	17.4237	4.1741	2.3610	3.1181	0.6175	0.7572	0.9320
	60	32	3.8118	17.7345	4.2112	2.3670	3.1385	0.6338	0.7715	0.9519
	62	34	3.8399	18.0414	4,2475	2.3663	3.1685	0.6640	0.8022	0.9927
	64	36	3.8572	18.3444	4.2830	2.4057	3.1370	0.6076	0.7314	0.9043
	66	38	---	18.6438	4.3178	2.4296	3.1279	0.5830	0.6983	0.8639
	68	40	---	18.9398	4.3519	2.4879	3.0629	0.4804	0.5750	0.7090

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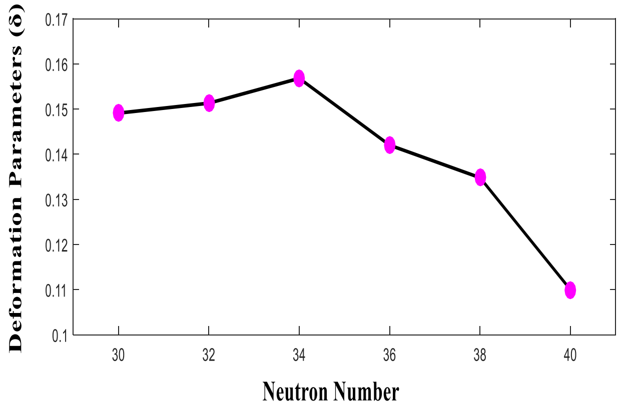

Figure 2. shows the relationship of the number of neutrons as a function of the distortion parameter δ for the element nickel ($_{28}$Ni).

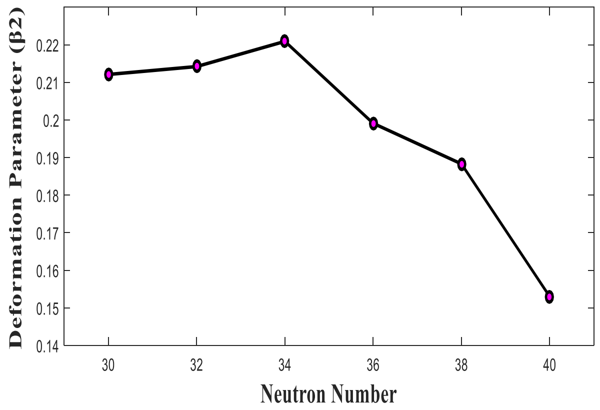

Figure 3. shows the relationship of the number of neutrons as a function of the distortion parameter β_2 for the element nickel ($_{28}$Ni).

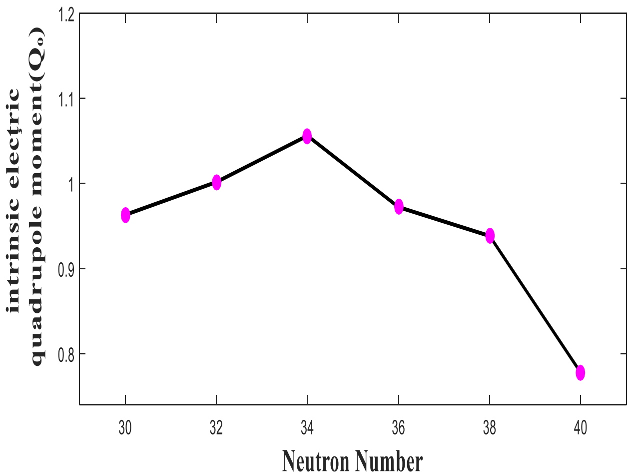

Figure 4. shows the relationship of the number of neutrons as a function of the intrinsic electric quadrupole moment(Q_0)for the element nickel ($_{28}$Ni)

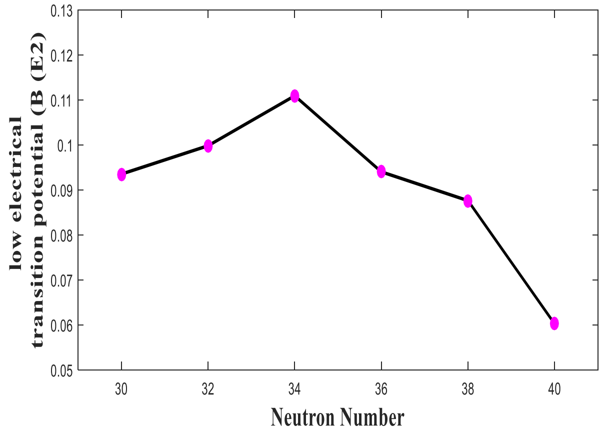

Figure 5. shows the relationship of the number of neutrons as a function of the low electrical transition potential (B (E2) for the element nickel ($_{28}$Ni)

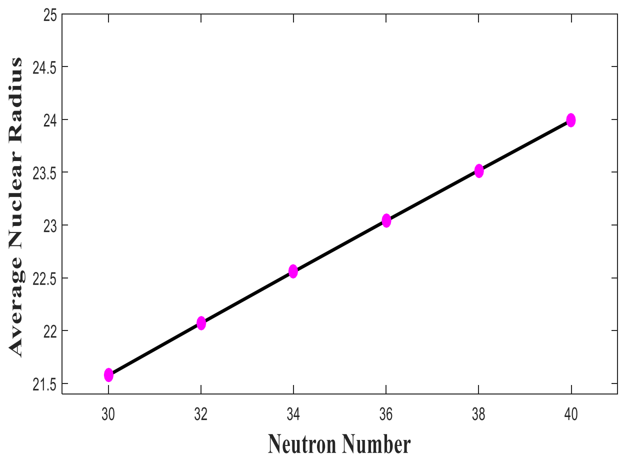

Figure 6. shows the relationship of the number of neutrons as a function of the average nuclear radius (R_0^2) for the element nickel ($_{28}$Ni).

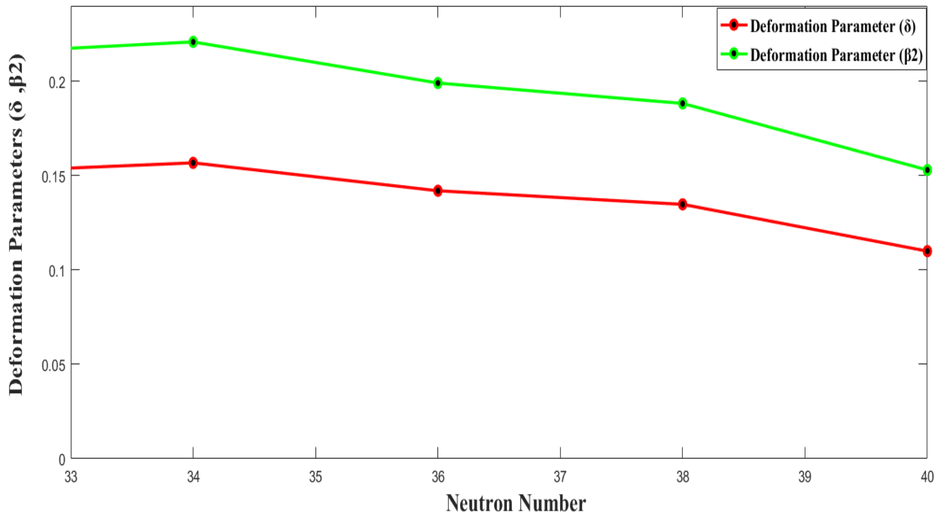

Figure 7. illustrates the relationship between the Deformation Parameters (δ,β2) for the element nickel ($_{28}$Ni) as a function of the number of neutrons.

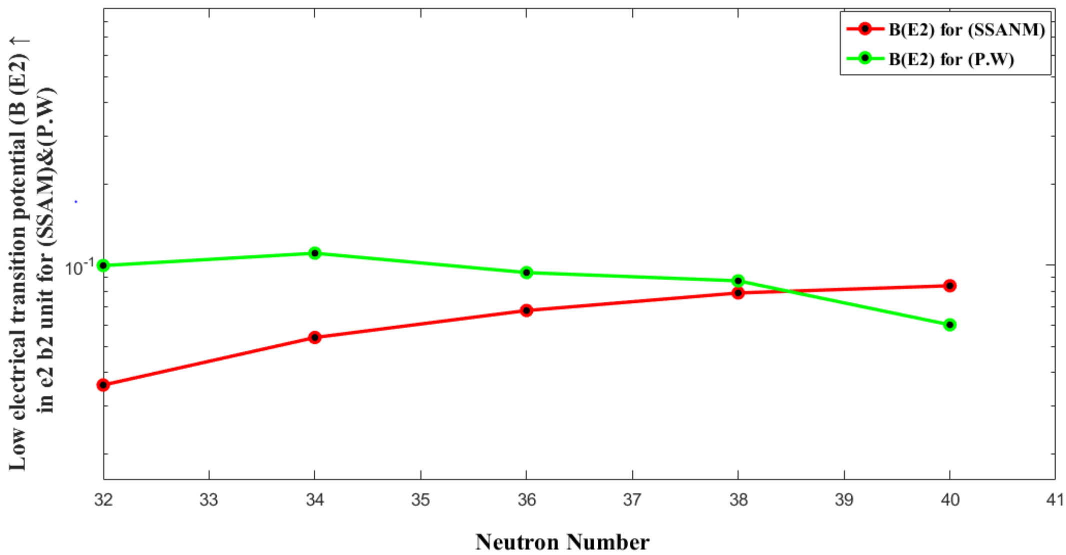

Figure 8. shows the relationship between Low electrical transition potential (B (E2) ↑ for (SSANM)&(P.W) in e^2 b^2 unit as a function of neutrons number for element nickel ($_{28}$Ni).

Conclusion

We conclude from the results obtained in the current study that the closer the nuclei, i.e. the atomic numbers or the number of neutrons for the nuclei, are to the magic numbers, the less distorted and more stable they are. Also, Nuclei show more stability and sphericality as the mass number *A* increases, and the energy of the first excited state (2+) steadily declines as *A* increases, except sites close to closed shells where energy values are rather high.

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Authors' Declaration

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours. Furthermore, any Figures and images, that are not ours, have been included with the necessary permission for re-publication, which is attached to the manuscript.
- No animal studies are present in the manuscript.
- No human studies are present in the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee at University of Sfax, Sfax, Tunisia.

Authors' Contribution Statement

S.A.E found the idea for the current study and it was the basis for choosing the topic, in addition to deducing an equation or relationship that was adopted in obtaining the results and drawings shown in the research. As for A.B.R was the first participant for S.A.E in the idea of the topic, in addition to providing the sources that were adopted in writing. S.M.I worked on writing the research and calculating and drawing the results. All authors participated in writing the introduction and discussing the calculations and conclusions that emerged from the study.

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حساب انصاف اقطار نظائر النيكل الزوجية-زوجية

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الخلاصة

ركز البحث الحالي على دراسة اشكال النوى زوجية-زوجية لنظائر النيكل والتي لها اعداد كتلية اقل من 100 حيث تم دراسة معاملات التشوه (β_2) والمشتقة من احتمالية الانتقال الكهربائي B(E2) وكذلك معاملات التشوه(δ) المشتقة من العزم الكهربائي رباعي القطب Q_0وتم دراسة متوسط مربع نصف القطر $< r^2 >^{1/2}$ بالاضافة الى المحاور الصغرى والكبرى (a,b) والفرق بينهما باستخدام معادلات نموذج القشرة المشوهة حيث تم ملاحظة الاختلاف في اشكال النوى لنظائر النيكل من خلال رسم اشكال ثلاثية وثنائية الابعاد ومن خلال النتائج التي تم الحصول عليها لوحظ ان النظائر الاكثر تشوها وميلا لعدم الاستقرار واتخاذ الشكل الاهليليجي هي النظائر ذات الاعداد النيترونات والبروتونات البعيدة عن الاعداد السحرية وكذلك تم مقارنة النتائج التي تم الحصول عليها مع النتائج النظرية من المصدر (SSANM) حيث لوحظ انها مقاربة لها نوعا ما.

الكلمات المفتاحية: احتمالية الانتقال (B(E2 :0+→2+، عزم الكهربائي رباعي القطب Q_o، معلمات التشوه (β_2، δ،) ، متوسط مربع توزيع الشحنة، نصف القطر $<r^2>$.