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Study of Excited Structure for Even-Even Nuclides of Z = 50, 48, 46 in The First Excited State

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بسم الله الرحمن الرحيم

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Rusul

Dedicate to

My Father and

Mother

Supervisor Certification

I certify that this thesis entitled ***"Study of Excited Structure for Even-Even Nuclides of Z = 50, 48, 46 in The First Excited State"*** was prepared under my supervision at the Department of Physics, College of Education for Pure Science / Ibn Al-Haitham, Baghdad University, as a partial fulfillment of the requirements for the degree of Master of Science in Physics / Nuclear Physics.

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Abstract

Electromagnetic properties for even-even nuclides in neutron-rich nuclei such $_{50}$Sn, $_{48}$Cd and $_{46}$Pd have been studied through the electric quadruple transition strength $|M(E2)|^2_{\,W.u} \downarrow$ and the reduced transition probability $B(E2)_{W.u} \downarrow$for γ_0-transition from first 2_1^+ excited state to the 0_1^+ ground state.

The electric quadruple transition strength $|M(E2)|^2_{\,W.u} \downarrow$ is calculated by using life-time for 2_1^+ excited state with the intensity of γ_0-transition, while $B(E2)_{W.u} \downarrow$ is extracted from half-life time to 2_1^+ state corrected for internal conversion coefficient.

To obtain precise value for the transition of $E2\downarrow$, the adopted value for $|M(E2)|^2_{\,W.u} \downarrow$ and $B(E2)_{W.u} \downarrow$ was calculated and plotted as a function for neutron number.

In present work, the adopted values for the transition of $E2\downarrow$ are converted to $B(E2)_{exp} \uparrow e^2b^2$ which helped us to study the structure for nucleus, such as the variation in shape, because the deformation parameter β is extracted from $B(E2) \uparrow e^2b^2$ and the study for behavior of each of $B(E2) \uparrow e^2b^2$ and β versus neutron number in isotonic chains to $_{50}$Sn, $_{48}$Cd and $_{46}$Pd gives good information about the deformation in nuclei.

Our study focused on the three different types of nuclei, the first with atomic magic number 50, the second with semi-magic atomic number 48 and the third nucleus with atomic number between closed shells 46.

At the end of the present work, the good comparisons for the present calculation to the values of the $B(E2) \uparrow e^2b^2$ and β with most recent values of experimental and theoretical was done.

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List of Abbreviations

Abbreviation	Meaning
γ	Gamma ray
L	Angular momentum
J_i	Initial total angular momentum
J_f	Final total angular momentum
E_{i}	Excited state energy
E_γ	Gamma ray energy
$E2$	Electric quadruple transition
τ	Mean life time
$t_{1/2}$	Half life time
A	Mass number
N	Neutron number
Z	Atomic number
h	Plank constant
$\hbar$	Reduced Plank constant
c	Velocity of light
π	parity
R	Nuclear radius
δ	Multipole mixing ratios
Γ_γ	Total gamma width
$\Gamma_\gamma\ (EorM,L)$	Partial gamma width
$\Gamma_{\gamma \mathrm{i}}$	Partial width of each gamma ray
T	Transition probability
$\mathrm{T}_\gamma\ (EorM,L)$	Partial gamma ray transition probability
$\mathrm{T_e}$	Conversion electrons transition probability

Abbreviation	Meaning
$I_{\gamma i}$	Relative intensity
I_{γ}	Total relative intensity of gamma-ray
I_{tot}	Total Intensity
I_e	Conversion electrons intensity
$\|M(EorM,L)\|^2$	Transition strength
$B(EorM,L)$	Reduced transition probability
$\alpha_{(K,L,M......)}$	Partial Internal conversion coefficient
α_{tot}	Total Internal conversion coefficient
β	Deformation parameter
Q_0	Intrinsic quadrupole moment
EL	Electric radiation
ML	Magnetic radiation
fm	Fermi
W.u	Weisskopf units
B.R	Branching ratios
S.p	Single particle
Ps	Pico second
GBF	Global Best Fit
SSANM	Single Shell Asymptotic Nilsson Model
FRDM	Finite-Range Droplet Model
et al.	And other authors

CHAPTER ONE

INTRODUCTION

Chapter One
Introduction

An atomic nucleus is the small, heavy, central part of atom consisting of a nucleons. It has two groups of particles: protons and neutrons each of these groups is separately distributed over certain energy states, and they are held together by their mutual interactions which turn out to be very complicated in detail.

One of the main objectives of study the nuclear physics is to understand the structure of nuclei, where the electromagnetic transition in nuclei has become widely used as a source of information about it.

The best studies for electromagnetic transitions modes in nuclei are those involving transition strength for gamma transition in even-even nuclei, which is an important parameter use to determine the relative importance of the collective and single-particle effect to describe the level structure of the nucleus and transitions modes, and gives us a good knowledge of the energies, spins, parties and life times of the excited states in nuclei.

1-1 Gamma-Ray Transition

An excited nucleus may lose energy by emitting a γ-ray photon whose energy E_γ is equal to the energy difference ΔE between the initial and final nuclear states. Gamma radiation is same as any other type of electromagnetic radiation in which a changing in electric field induces a magnetic field and vice versa [1].

For a γ-transition from an initial state of spin (total angular momentum) J_i and parity π_i to a final state of spin J_f and parity π_f, the transition by emission of a single 2^L-pole quantum is possible if :

$$\left| J_i - J_f \right| \;\le\; L \;\le\; J_i + J_f \qquad\qquad (L \neq 0) \qquad ...(1.1)$$

Where L is the angular momentum of the γ-transition.

In such transitions, the parity change of electric radiation, EL, is given by :

$$\pi_i \cdot \pi_f = (-1)^L \qquad ...(1.2)$$

And for magnetic radiation, ML, by :

$$\pi_i \cdot \pi_f = (-1)^{L+1} \qquad ...(1.3)$$

If the initial and final parities are equal, then *M1*, *E2*, *M3*, *E4*, *M5*, etc. will conserve parity. if the parities of the initial and final states are different, then, *E1*, *M2*, *E3*, *M4*, *E5*, etc, are possible [2].

For the case in which either J_i or J_f is equal to zero, only a pure multipole transition is emitted, for example, the first excited state is 2^+ (J_i = 2, π_i = even) (even Z, even N) nuclei decays to the 0^+ ground state (J_f = 0, π_f = even) through the emission of a pure electric quadrupole *E2* transition because the above (1.1, 1.2, 1.3) selection rules gives immediately $L = 2$ [3].

We have already noted that $L = 0$ for γ-transition is not allowed because photons with zero angular momentum does not exist, thus the transition is forbidden between two spin-zero states i.e. ($J_i = J_f = 0$) [1].

The single-particle Weisskopf estimates permit us to make some general predictions about which multipole is most likely to be emitted [4], where the transition associated with each of the possible L values has a partial decay constant [$T_\gamma\,(EL)$ or $T_\gamma\,(ML)$] that describes the probability for such a transition to occur. The Weisskopf estimates has been derived for approximating transition probabilities as functions of mass number A and γ-ray energy E_γ [5].

The Weisskopf estimates are [4] :

$$T_\gamma(E1) = 1.0\times10^{14} A^{2/3} E_\gamma^3 \qquad ...(1.4)$$

$$T_\gamma(E2) = 7.3\times10^{7} A^{4/3} E_\gamma^5 \qquad ...(1.5)$$

$$T_\gamma(E3) = 3.4\times10\ A^{2} E_\gamma^7 \qquad ...(1.6)$$

$$T_\gamma(E4) = 1.1\times10^{-5} A^{8/3} E_\gamma^9 \qquad ...(1.7)$$

$$T_\gamma(M1) = 5.6\times10^{13}\ E_\gamma^3 \qquad ...(1.8)$$

$$T_\gamma(M2) = 3.5\times10^{7} A^{2/3} E_\gamma^5 \qquad ...(1.9)$$

$$T_\gamma(M3) = 1.6\times10\ A^{4/3} E_\gamma^7 \qquad ...(1.10)$$

$$T_\gamma(M4) = 4.5\times10^{-6} A^{2} E_\gamma^9 \qquad ...(1.11)$$

Where T_γ has units of s^{-1} and E_γ is in MeV.

Based on the above single-particle estimates, the lowest possible multipolarity is the most probable for a given transition type (*E* or *M*) [6].

1-2 Gamma-Ray Reduced Transition Probabilities and Strengths

Reduced transition probabilities play an important role in nuclear physics and are in high demand for nuclear model calculations [7].

The Weisskopf single-particle reduced transition probability $B(E\text{or}M,L)_{\text{W.u}}$ is defined as the ratio of single-particle half-life time to experimental half-life time for γ-transition [8] :

$$B\,(EorM\ ,L\,)_{\mathrm{W.u}} = \frac{t_{1/2}\,(\gamma)(EorM\ ,L\,)_{S.p}}{t_{1/2}\,(\gamma)(EorM\ ,L\,)_{\exp}} \qquad ...(1.12)$$

The reduced transition probability has long been a basic observable in the extraction of the magnitude of nuclear deformation or in probing anomalies in the nuclear structure [9] .

While the γ-ray transition strength $|M(EorM,L)|^2{}_{\mathrm{W.u}}$ is defined as the ratio of experimental gamma width to gamma width in Weisskopf units [10] :

$$\left|M\ (EorM\ ,L\,)\right|^2_{\mathrm{W.u}} = \frac{\Gamma\left(EorM\ ,L\,\right)_{\exp}}{\Gamma\left(EorM\ ,L\,\right)_{\mathrm{W.u}}} \qquad ...(1.13)$$

With recent advances in techniques for supplying intense beams of unstable nuclei, several exotic properties such as magicity loss have been discovered in neutron-rich nuclei through measurements of transition strength [9] . More details are given in chapter two.

1-3 Multipole Mixing Ratios (δ)

The study of multipole mixing ratios δ of γ-rays from excited nuclear states have been the subject of interest for many experimental and theoretical investigations. Experimentally, δ -values can be derived mainly from angular distribution measurements [11] .

Theoretically, the multipole mixing ratios for *E2*, and *M1* mixed transition can be defined as the ratio of the electric quadrupole *E2* to magnetic dipole *M1* matrix elements for γ-transition from an initial state J_i to final state J_f :

$$\delta = \frac{\left\langle J_f \,\|E\,2\|\, J_i \right\rangle}{\left\langle J_f \,\|M\,1\|\, J_i \right\rangle} \qquad ...(1.14)$$

Measurements of *E2/M1* mixing ratios of γ-transitions in even-even nuclei have long provided important tests to nuclear models and provide the most accurate results for comparisons with theoretical calculations based on different nuclear models [12] .

The mixing ratio δ^2 , can also be defined as follows [8] :

$$\delta^2 = \frac{I_\gamma(L+1)}{I_\gamma(L)} \qquad ...(1.15)$$

Where I_γ *(L)* and I_γ *(L*+1) are the relative intensities of γ-rays transition from certain level with mixed multipolarities *L* and *L*+1, then the total relative gamma intensity I_γ is given by :

$$I_\gamma = I_\gamma(L) + I_\gamma(L+1) \qquad ...(1.16)$$

1-4 Gamma-Ray Branching Ratios [*B.R*(γ*i*)]

If two or more γ-rays de-excited from the same state, then the branching ratio of ith γ-rays transition is given by [13] :

$$B.R(\gamma_i) = \frac{I_{\gamma i}}{I_{tot}} \times 100\% \qquad ...(1.17)$$

Where $I_{\gamma i}$ is the relative intensity of γ_i.

$I_{tot} = \sum I_{\gamma i}$ (summation for all γ-rays de-excited from certain level).

Other expression for *B.R* (γ_i) can be used as suggested by [14] :

$$B.R(\gamma_i) = \frac{\Gamma_{\gamma i}}{\Gamma_\gamma} \qquad ...(1.18)$$

Where $\Gamma_{\gamma i}$ is the partial width of each γ-ray.

1-5 Internal Conversion

The internal conversion process is an alternative decay mode to γ-ray emission [15], it is a radioactive decay process where an excited nucleus interacts with an electron in one of the lower atomic shell (*K*, *L*, *M* ...) causing the electron to be emitted from the atom. Thus, in an internal conversion process, a high-energy electron is emitted from the excited atom [16]. After the electron has been emitted, the atom is left with a vacancy in one of the inner electron shells. This hole will be filled with an electron from one of the higher shells and subsequently a characteristic x-ray or Auger electron will be emitted.

The tendency towards understanding the internal conversion occurs by conversion coefficient calculation [4], which is used to determine the angular momentum and parity changes of the states involved in the transition [15], it can be defined as the ratio of de-excitations that go by the emission of electrons to those that go by γ-ray emission i.e. :

$$\alpha = \frac{I_e}{I_\gamma} = \frac{T_e}{T_\gamma} \qquad ...(1.19)$$

where α is the internal conversion coefficient, I_e is the intensity of conversion electrons and I_γ is the intensity of γ-ray emission observed from a decaying nucleus, while T_e is the decay probability by the conversion electrons and T_γ is the decay probability by γ-ray emission [4].

1-6 Deformed Nuclei

Nuclear shapes are indeed extremely useful to understand nuclear dynamics and the quest regarding shapes of nucleus fascinated scientists for many years. Although many nuclei are spherical but majority of them exhibit essentially not just one shape, but different shapes [17].

It is well established that many nuclei with N and Z values between magic numbers are permanently deformed in their shape, the deformation arises because of the way valence nucleons arrange themselves in an unfilled shell, in other words the deformation happens only when both proton and neutron shells are partially filled [18] .

In general, the nucleus is considered to have spherical shape, but if the distribution of charges in the nucleus is not spherically symmetric, the nucleus will have quadrupole moment, such nuclei may be prolate ellipsoidal which has positive quantity of quadrupole moment.

Or oblate ellipsoidal which has negative quantity of quadrupole moment as noticed in figure (1-1) [17] .

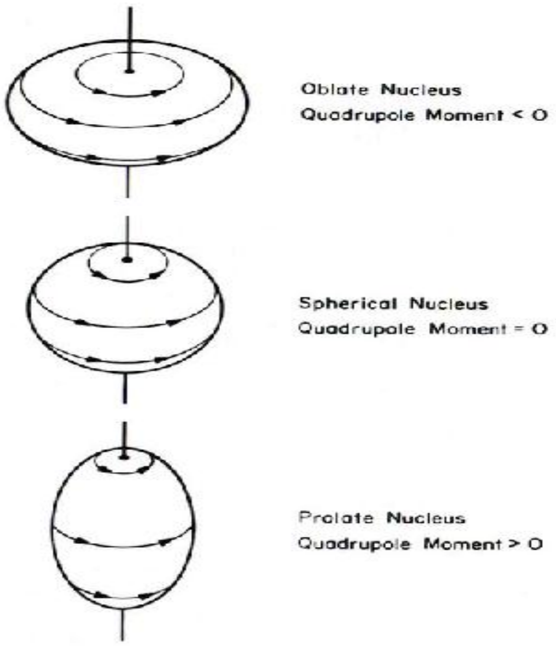

Figure (1-1): Shapes of deformed nuclei [17].

The degree of which a nucleus is deformed is described by the deformation parameter which is given by [19] :

$$\beta = \frac{4}{3}\left(\frac{\pi}{5}\right)^{1/2} \frac{\Delta R}{R_{\text{av}}} \qquad ...(1.20)$$

Where β is the deformation parameter in relation to the eccentricity an ellipsoidal nucleus.

ΔR is the difference between the semi-major and semi-minor axis of the ellipse.

$R_{\text{av}} = \text{average radius} = 1.3 \times 10^{-15}\ A^{1/3}\ \text{m}$

when β = 0 the nucleus is spherical, When β > 0 the nucleus has the elongated form of a prolate ellipsoid, and When β < 0 the nucleus has the flattened form of an oblate ellipsoid [20].

1-7 Previous Studies

Ibbotson R.W. *et al.* (1998) [21] studied the excited states at 1399± 25 keV and 1084± 20 keV for the first time in ^{36,38}Si. The $B(E2;\ 0_1^+ \rightarrow 2_1^+)$ values leading to these states and the previously identified 2^+ states in ^{32,34}Si have been measured, and are compared to shell model calculations.

Raman S. *et al.* (2001) [22] collected experimental values for the reduced electric quadrupole transition probability $B(E2)\uparrow$ between the 0^+ ground state and the first excited state 2^+ in even-even nuclides and given in tables for theoretical physicists to test their predicated values which were extracted from different nuclear models.

Mehmet Baylan and Ihsan Uluer (2002) [23] used the Rotation-Vibration Model approach to calculate the multipole mixing ratios δ (*E2*/*M1*), deformation parameter, and quadrupole moments for ^{156}Gd nucleus.

Deloncle I. and Roussiere B. (2004) [24] showed that the reduced transition probability $B(E2;\ 0_1^+ \rightarrow 2_1^+)$ of even-even nuclei can be related to the product of the number of particles by the number of holes of the valence space. This very simple expression is used to analyze at the same time the experimental $B(E2)\uparrow$ values of $^{56-68}$Ni and those of $^{62-72}$Zn.

Grawe H. *et al.* (2005) [25] used Coulombs excitation experiments to measure the reduced transition probabilities $B(E2;\ 0_1^+ \rightarrow 2_1^+)$ for the first time in the neutron rich ^{68}Ni and ^{70}Ni nuclei. These data give different behavior of the $B(E2)\uparrow$ values in the Ni isotopes versus neutron number.

Ilyas Inci and Nurettin Turkan (2006) [26] estimated energy levels and multipole mixing ratios δ (*E2*/*M1*) for doubly-even $^{102\text{-}110}$ Pd nuclei using interacting boson model (IBM-2). The results are compared with previous experimental and theoretical data and it is observed that they are in good agreement.

Boboshin I. *et al.* (2007) [27] deformation parameters are obtained by two different methods: nuclear quadrupole moments Q (“Q-type” data) and from reduced transition probability $B(E2;\ 0_1^+ \rightarrow 2_1^+)$ (“B-type” data) for two groups of nuclides: group1 (Ti, Cr, Zr, Nd, Sm, Gd, Dy, Er, W, Os, Ra), group2 (C, Si, Ar, Ca, Fe, Ni, Zn, Ge, Se, Kr, Sr, Mo, Ru, Pd, Cd, Sn, Te, Ba, Yb, Hf, Pt, Pb). It shows that (B-type) data values are systematically larger than (Q-type) ones .

Ali Abdulwahab.R. (2009) [28] studied the nuclear deformation parameters of even-even Zirconium $^{80-104}Zr$ isotopes using deformed and spherical shell model and corresponding to reduced transition probability $B(E2;\ 0_1^+ \rightarrow 2_1^+)$.

Thomas Behrens (2009) [29] the $B(E2;\ 0_1^+ \rightarrow 2_1^+)$ values of neutron-rich $^{122-126}Cd$ (N < 82) and $^{138-144}Xe$ (N > 82) isotopes both below and above the shell closure at N = 82 have been measured by coulomb excitation. The values of $^{124,126}Cd$ and $^{138,142,144}Xe$ have been measured for the first time. For $^{140,142}Xe$ the $B(E2;\ 2^+ \rightarrow 4^+)$ has also been determined, and the quadrupole deformation for $^{138-144}Xe$ have been taken into account.

Meeran (2010) [30] studied the electromagnetic features which are observed in the nuclei of atomic number between Z =18-44 and neutron number N=22-68 through the transitions $2^+ \rightarrow 0^+_{g.s}$.

Kumar R. *et al.* (2011) [31] the poorly known $B(E2;\ 0_1^+ \rightarrow 2_1^+)$ values of ^{112}Sn and ^{114}Sn have been measured to high precision. Two Coulomb excitation experiments were performed to determine the reduced transition probabilities relative to ^{116}Sn in order to minimize the systematic errors. The obtained $B(E2)\uparrow$ values of 0.242(8) e^2b^2 for ^{112}Sn and 0.232(8) e^2b^2 for ^{114}Sn confirm the tendency of large $B(E2)\uparrow$ values for the lighter tin isotopes below the midshell ^{116}Sn that has been observed recently in various radioactive ion beam experiments.

Anagnostatou V. *et al.* (2011) [32] electromagnrtic transition rates have been measured for decays from the ground state band in the transitional nucleus ^{100}Pd. The lifetime for the 2^+ state in ^{100}Pd is deduced to be 13.3(9) Ps, which corresponds to a $B(E2;\ 2_1^+ \rightarrow 0_1^+)$ of 17.2(1.2) in W.u.

Kibedi T. *et al.* (2011) [33] the internal conversion coefficients for Z =111 to Z =126 super heavy elements was obtained. The new conversion coefficient data tables presented here cover all atomic shells transition energies from 1 keV up to 6000 keV.

Abdullah H.Y. *et al.* (2011) [34] studied the systematic 8^+ isomeric levels, half-lives, deformation parameters, and reduced transition probabilities between $8^+ \rightarrow 6^+$ state of even-even ^{76}Ni to ^{94}Pd nuclei for N = 48 neutrons. The calculated half-lives and quadrupole moments are compared with the experimental values, and studied the systematic $B(E2)$ values, intrinsic quadrupole moments as a function of atomic number Z for N = 48 neutrons.

Bauer C. *et al.* (2012) [35] lifetimes of states of ^{132}Ba and ^{140}Ba were obtained for the first time as well as the static electric quadrupole moments $Q(2_1^+)$ for ^{130,132}Ba and ^{140,142}Ba. The $B(E2;\ 2_1^+ \rightarrow 0_1^+)$ values of

^{140}Nd and ^{142}Sm are calculated and compared to the shell-model calculations.

Vijay Sai K. *et al.* (2012) [36] mixing ratios have been determined for all the *M1*+*E2* transitions in ^{131}Xe for (E_γ = 80.179, 177.21, 272.5, 318.07, 325.76, 364.48, 404.83, 722.9) in KeV using the experimental α_K values and the corresponding BRICC values for *M1* and *E2* multipolarities. The experimental *B*(*E2*) values were calculated from the present mixing ratios and α values and the life times of the corresponding states from the literature.

Fouad A.Majeed (2012) [37] study the low lying 2^+ and 4^+ energies and the $B(E2;\ 0_1^+ \rightarrow 2_1^+)$ for even-even $^{20\text{-}32}$Mg isotopes, good agreement was obtained in comparing with the recent available experimental and theoretical. The $B(E2;\ 2_1^+ \rightarrow 0_1^+)$ values for Mg isotopes are more closer to the experimental values.

Hossain I. *et al.* (2012) [38] measured the electric quadrupole reduced transition probabilities *B*(*E2*) between 6^+ to 4^+ and 4^+ to 2^+ states of ^{114,116,118,122}Cd isotopes using interacting boson model (IBM-1). The values of reduced transition probabilities of ^{114,116,118,122}Cd nuclei from transitions 4^+ to 2^+ and 6^+ to 4^+ are (0.180 and 0.237) e^2b^2, (0.197 and 0.253) e^2b^2, (0.194 and 0.243) e^2b^2, (0.143 and 0.168) e^2b^2, respectively. In addition, the systematic *B*(*E2*) values are studied as a function of neutron numbers from N = 66, 68, 70, 74. The calculated results of *B*(*E2*) are in good agreement with experimental values.

Khalid H.H. Al-Attiah *et al.* (2013) [39] studied the excitation energies and transition rates $B(E2;\ 2_1^+ \rightarrow 0_1^+)$ for even-even $^{102\text{-}108}$Sn nuclei using shell model.

1-8 The Aim of the Present Work

The present work is aimed to study the nuclear structure for some even-even nuclei through the electric quadrupole transition strengths $|M(E2)|^2_{\text{W.u}}$ and reduced transition probabilities $B(E2)_{\text{W.u}}$ for γ_0-transition from first excited 2_1^+ state to the 0_1^+ ground state.

The good information about the behavior for $|M(E2)|^2_{\text{W.u}}$ and $B(E2)_{\text{W.u}}$ versus neutron number obtained for the following nuclei :

1- $_{46}$Pd $102 \le A \le 116$

2- $_{48}$Cd $106 \le A \le 118$

3- $_{50}$Sn $112 \le A \le 124$

Furthermore, there is another property related to reduce transition probability which has been calculated such as the deformation parameters for these nuclei. The obtained results are discussed and compared with the previous results.

CHAPTER TWO

THEORY

Chapter Two
Theory

2-1 Gamma-Ray Transition Probability

For γ-ray transition between two nuclear states with spins J_i and J_f , the transition probabilities of electric 2^L (EL) and magnetic 2^L (ML) transitions can be written as [8] :

$$T_\gamma(EL)=\frac{8\pi(L+1)e^2b^L}{L[(2L+1)!!]^2\hbar}\left[\frac{E_\gamma}{\hbar c}\right]^{2L+1}B(EL)\downarrow \qquad ...(2.1)$$

And

$$T_\gamma(ML)=\frac{8\pi(L+1)\mu_N^2b^{L-1}}{L[(2L+1)!!]^2\hbar}\left[\frac{E_\gamma}{\hbar c}\right]^{2L+1}B(ML)\downarrow \qquad ...(2.2)$$

The constants in these equations are:

$h=\text{Plank constant}=4.13566\times10^{-18}\ \text{KeV. s}$

$\hbar=\text{Reduced Plank constant}=\dfrac{h}{2\pi}=6.58212\times10^{-19}\ \text{KeV. s}$

$c=\text{velocity of light}=3\times10^{10}\ \text{cm / s}$

$e^2=1.440\times10^{-10}\ \text{KeV. cm}$ (e = electron charge)

$\mu_N^2=1.5922\times10^{-38}\ \text{KeV. cm}^3$ (μ_N = nuclear magneton)

$b=\text{barn}=10^{-24}\ \text{cm}^2$

It is obvious from equations (2.1 and 2.2) that the transition probability decreases drastically with higher multipole order L [40], it also becomes clear that the transition probability increases rapidly with the transition energy [16] .

$B(EL)\downarrow$ and $B(ML)\downarrow$ are the reduced downward probabilities for electric and magnetic transitions respectively. These reduced downward probabilities may be calculated with the theoretical model for comparison with experiment [11] .

Weisskopf has derived the following single particle estimates using the shell model [5] :

$$B_{S.p}(EL) = B_{\mathrm{W.u}}(EL) = \frac{1}{4\pi b^{L}}\left[\frac{3}{3+L}\right]^{2} R^{2L} \qquad ...(2.3)$$

$$B_{S.p}(ML) = B_{\mathrm{W.u}}(ML) = \frac{10}{\pi b^{L-1}}\left[\frac{3}{3+L}\right]^{2} R^{2L-2} \qquad ...(2.4)$$

Where $R = \text{radius of the nucleus} = 1.2\times10^{-13}A^{1/3}$ cm

The reduced Weisskopf single-particle transition probability in a comparison with experimental and theoretical γ-ray transitions probabilities is given by [41] :

$$B(EorM\ ,L)_{\mathrm{W.u}} = \frac{B(EorM\ ,L)_{\exp}}{B(EorM\ ,L)_{S.p}} \qquad ...(2.5)$$

Numerical values for $B(E\mathrm{or}M,L)_{\mathrm{W.u}}$ for different multipole transitions are given in the following equations [42] :

$$B(E1)_{\mathrm{s.p}}\downarrow = 0.06446\ A^{2/3}\ \mathrm{e}^{2}(fm)^{2} \qquad ...(2.6)$$

$$B(E2)_{\mathrm{s.p}}\downarrow = 0.05940\ A^{4/3}\ \mathrm{e}^{2}(fm)^{4} \qquad ...(2.7)$$

$$B(M1)_{\mathrm{s.p}}\downarrow = 1.7905\ \mu_{N}^{2} \qquad ...(2.8)$$

$$B(M2)_{\mathrm{s.p}}\downarrow = 1.6501\ A^{2/3}\ \mu_{N}^{2} \qquad ...(2.9)$$

The transition probability can also be given by [8] :

$$T = \frac{1}{\tau} \qquad ...(2.10)$$

Where τ is the mean life time of the initial state and is given by :

$$\tau = \frac{t_{1/2}}{\ln 2} \qquad ...(2.11)$$

So :

$$T = \frac{\ln 2}{t_{1/2}} \qquad ...(2.12)$$

For the K_{th} γ-ray of n γ-rays de-exciting level, the partial half-life time for γ-ray emission $t_{1/2}(\gamma)$ is related to the level half-life time $t_{1/2}$ by [8]

$$t_{1/2}(\gamma) = t_{1/2} \sum_{i=1}^{n} \left(I_i^{\gamma}\right) \frac{(1+\alpha_i)}{I_k} \qquad ...(2.13)$$

Where the summation is over the intensity I_i^{γ} of all γ-rays de-exciting the level, corrected for the internal conversion coefficient α_i , I_k is the intensity of K_{th} γ-ray.

If there is only one gamma transition from $j^{\pi} = 2^+$ state to $j^{\pi} = 0^+$ with intensity 100% the eq.(2.13) becomes [43] :

$$t_{1/2}(\gamma)_{\exp} = t_{1/2}(1+\alpha_{tot}) \qquad ...(2.14)$$

where α_{tot} is the total internal conversion coefficient.

From equations (2.12, 2.3 and 2.1) :

$$t_{1/2}(\gamma)(EL)_{\mathrm{W.u}} = \frac{\ln 2}{2} \frac{L[(2L+1)!!]^2 \hbar}{(L+1)e^2 R^{2L}} \left[\frac{3+L}{3}\right]^2 \left[\frac{\hbar c}{E_{\gamma}}\right]^{2L+1} \qquad ...(2.15)$$

And from equations (2.12, 2.4 and 2.2) :

$$t_{1/2}(\gamma)(ML)_{\text{W.u}} = \frac{\ln 2}{80}\frac{L[(2L+1)!!]^2\hbar}{(L+1)\mu_N^2 R^{2L-2}}\left[\frac{3+L}{3}\right]^2\left[\frac{\hbar c}{E_\gamma}\right]^{2L+1} \qquad ...(2.16)$$

Formula for single-particle transition half-life times, corrected for internal conversion are as follows [8] :

$$t_{1/2}(\gamma)(E1)_{\text{W.u}} = \frac{6.7622\times10^{-6}}{E_\gamma^3 A^{2/3}} \qquad ...(2.17)$$

$$t_{1/2}(\gamma)(E2)_{\text{W.u}} = \frac{9.5235\times10^{6}}{E_\gamma^5 A^{4/3}} \qquad ...(2.18)$$

$$t_{1/2}(\gamma)(E3)_{\text{W.u}} = \frac{2.0442\times10^{19}}{E_\gamma^7 A^{2}} \qquad ...(2.19)$$

$$t_{1/2}(\gamma)(E4)_{\text{W.u}} = \frac{6.5003\times10^{31}}{E_\gamma^9 A^{8/3}} \qquad ...(2.20)$$

$$t_{1/2}(\gamma)(M1)_{\text{W.u}} = \frac{2.2017\times10^{-5}}{E_\gamma^3} \qquad ...(2.21)$$

$$t_{1/2}(\gamma)(M2)_{\text{W.u}} = \frac{3.1007\times10^{7}}{E_\gamma^5 A^{2/3}} \qquad ...(2.22)$$

$$t_{1/2}(\gamma)(M3)_{\text{W.u}} = \frac{6.6556\times10^{19}}{E_\gamma^7 A^{4/3}} \qquad ...(2.23)$$

$$t_{1/2}(\gamma)(M4)_{\text{W.u}} = \frac{2.1164\times10^{32}}{E_\gamma^9 A^{2}} \qquad ...(2.24)$$

In equations (2.15 to 2.24), $t_{1/2}$ is in second and E_γ in KeV.

For γ-transitions with mixed multipolarities L and L+1, the γ-ray half-life time becomes [8] :

$$t_{1/2}(\gamma)^{L}=t_{1/2}(\gamma)\times\left(1+\delta^{2}\right) \qquad ...(2.25)$$

$$t_{1/2}(\gamma)^{L+1}=t_{1/2}(\gamma)\times\frac{\left(1+\delta^{2}\right)}{\delta^{2}} \qquad ...(2.26)$$

Then the multipolarities mixing ratio is given by the expression :

$$\delta^{2}=\frac{t_{1/2}(\gamma)^{L}}{t_{1/2}(\gamma)^{L+1}} \qquad ...(2.27)$$

2-2 Gamma-Ray Transition Strength

From equation (1.13) the γ-ray transition strength $|M|^2_{\mathrm{W.u}}$ can be written as :

$$|M|^{2}_{\mathrm{W.u}}=\frac{\Gamma_{\exp}}{\Gamma_{\mathrm{W.u}}} \qquad ...(2.28)$$

The partial width of γ-ray transition from an initial state with spin J_i to final state with spin J_f is given by [10] :

$$\Gamma_{\gamma L}=\frac{8\pi(L+1)}{L[(2L+1)!!]^{2}}\left[\frac{E_{\gamma}}{\hbar c}\right]^{2L+1}B(L)\downarrow \qquad ...(2.29)$$

If the total width for gamma decay is [10] :

$$\Gamma_{\gamma}=\sum\Gamma_{\gamma L} \qquad ...(2.30)$$

Then :

$$\Gamma_{\gamma}=\frac{\hbar}{\tau} \qquad ...(2.31)$$

For γ-transitions with mixed multipolarities L and L+1, the total gamma width becomes [8] :

$$\Gamma_\gamma = \Gamma(L) + \Gamma(L+1) \qquad ...(2.32)$$

Then the multipolarities mixing ratio can obtained from eqs.(2.31,2.27) :

$$\delta^2 = \frac{\Gamma(L+1)}{\Gamma(L)} \qquad ...(2.33)$$

For pure electric dipole *E1* or pure quadrupole transition *E2*, δ =0 and hence :

$$\Gamma(E1) \text{or } \Gamma(E2) = \Gamma_\gamma \qquad ...(2.34)$$

The transition strength for pure *E2* transition can be obtained using eq.(1.13) in the form :

$$|M(E2)|^2_{\text{W.u}} = \frac{\Gamma(E2)_{\text{exp}}}{\Gamma(E2)_{\text{W.u}}} \qquad ...(2.35)$$

The following values for the partial gamma widths in Weisskopf units, can be obtained on the basis of an extreme single particle model where E_γ in KeV, $\Gamma_{\gamma \text{W.u}}$ in eV [8] :

$$\Gamma_{\gamma \text{W.u}}(E1) = 6.7469 \times 10^{-11} A^{2/3} E_\gamma^3 \qquad ...(2.36)$$

$$\Gamma_{\gamma \text{W.u}}(E2) = 4.7907 \times 10^{-23} A^{4/3} E_\gamma^5 \qquad ...(2.37)$$

$$\Gamma_{\gamma \text{W.u}}(E3) = 2.2319 \times 10^{-35} A^{2} E_\gamma^7 \qquad ...(2.38)$$

$$\Gamma_{\gamma \text{W.u}}(E4) = 7.0187 \times 10^{-48} A^{8/3} E_\gamma^9 \qquad ...(2.39)$$

$$\Gamma_{\gamma \text{W.u}}(M1) = 2.0722 \times 10^{-11} E_\gamma^3 \qquad ...(2.40)$$

$$\Gamma_{\gamma \mathrm{W.u}}(M\,2) = 1.4714 \times 10^{-23} A^{2/3}\ E_{\gamma}^{5} \qquad ...(2.41)$$

$$\Gamma_{\gamma \mathrm{W.u}}(M\,3) = 6.8550 \times 10^{-36} A^{4/3}\ E_{\gamma}^{7} \qquad ...(2.42)$$

$$\Gamma_{\gamma \mathrm{W.u}}(M\,4) = 2.1557 \times 10^{-48} A^{2}\ E_{\gamma}^{9} \qquad ...(2.43)$$

From equations.(1.12, 1.13, 2.5 , 2.11 and 2.31) it can be concluded for *E2* transition :

$$\begin{aligned} |M\ (E\,2)|^2_{\mathrm{W.u}} &= \frac{\Gamma(E\,2)_{\exp}}{\Gamma(E\,2)_{\mathrm{W.u}}} = \frac{t_{1/2}(\gamma)(E\,2)_{S.p}}{t_{1/2}(\gamma)(E\,2)_{\exp}} \\ |M\ (E\,2)|^2_{\mathrm{W.u}} &= B\,(E\,2)_{\mathrm{W.u}} = \frac{B\,(E\,2)_{\exp}}{B\,(E\,2)_{S.p}} \end{aligned} \qquad ...(2.44)$$

Where $t_{1/2}$ (γ) $(E2)_{\exp}$ corrected for internal conversion coefficient as in eq.(2.14).

With the aid of equations (2.44, 2.3) can be obtained :

$$|M\ (EL\,)|^2_{\mathrm{W.u}} = 4\pi b^{L}\ \frac{B\,(EL\,)_{\exp}}{\left[3/(3+L\,)\right]^2 R^{\,2L}} \qquad ...(2.45)$$

And from equations (2.44, 2.4) can be obtained :

$$|M\ (ML\,)|^2_{\mathrm{W.u}} = \frac{\pi b^{\,L-1}}{10}\,\frac{B\,(ML\,)_{\exp}}{\left[3/(3+L\,)\right]^2 R^{\,2L-2}} \qquad ...(2.46)$$

Inserting the value R=1.2 $A^{1/3}$ fm in eq.(2.45, 2.46),one obtains [44] :

$$|M\ (E\,1)|^2_{\mathrm{W.u}} = \frac{15.5}{A^{2/3}} \cdot \frac{B\,(E\,1)}{e^2 \cdot fm^2} = \frac{1550 B\,(E\,1)}{A^{2/3} e^2 b} \qquad ...(2.47)$$

$$|M\ (E\,2)|^2_{\mathrm{W.u}} = \frac{16.8}{A^{4/3}} \cdot \frac{B\,(E\,2)}{e^2 \cdot fm^4} = \frac{16.8 \times 10^4}{A^{4/3}} \cdot \frac{B\,(E\,2)}{e^2 b^2} \qquad ...(2.48)$$

2-3 The Relation Between Upward and Downward *B*(*E2*)

Suppose two nuclear states, J_i is the spin of the initial state and J_f is spin of the final state as in figure (2-1).

The relation between the reduced transition probabilities is given by [45] :

$$B(E2)\uparrow = \frac{2J_f + 1}{2J_i + 1} B(E2)\downarrow \qquad ...(2.49)$$

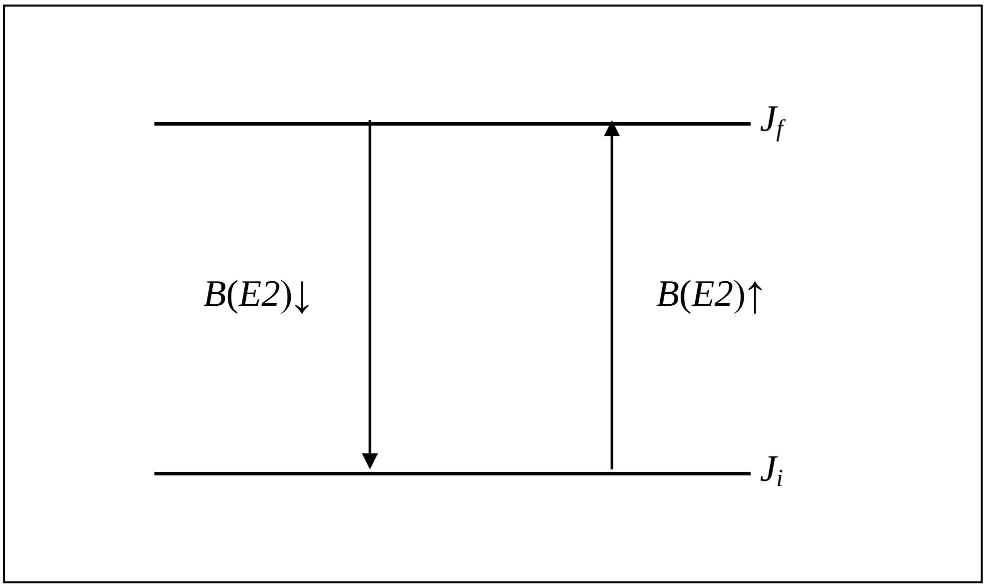

Figure (2-1): The upward and downward electric quadrupole reduced transition probabilities.

2-4 Internal Conversion Coefficient

The internal conversion coefficient can be written as a sum of partial coefficients each of which corresponds to the particular atomic shell of the emitted electron (*K*, *L*, *M*.....), thus [1] :

$$\alpha_{tot}\left(EorM\ ,L\right)=\alpha_{K}\left(EorM\ ,L\right)+\alpha_{L}\left(EorM\ ,L\right) \\ +\alpha_{M}\left(EorM\ ,L\right)+\cdots \qquad ...(2.50)$$

If the electrons from different orbits in the L shell, the α_L conversion coefficient can be further partitioned as [1] :

$$\alpha_L=\alpha_{LI}+\alpha_{LII}+\alpha_{LIII} \qquad ...(2.51)$$

Recently the internal conversion coefficient has become widely used as a source of information about the structure of nuclear levels. The multipole mixing ratio δ for γ-transition from excited levels can be calculated by using total conversion coefficient, in a mixed transition as follows [46] :

$$\alpha_{tot}=\frac{\alpha\left(EorM\ ,L\right)+\alpha\left(EorM\ ,L+1\right)\delta^2}{1+\delta^2} \qquad ...(2.52)$$

while in present work, the internal conversion coefficient was used to calculate $B(E2)\uparrow$ values for pure *E2* transition as mentioned previously in eq.(2.14) and eq.(2.44).

2-5 Deformation Parameter Evaluation from Reduced Transition Probability

Deformation parameter β can be related to the electric quadrupole reduced transition probability $B(E2)$ by the formula [47] :

$$\beta = \frac{4\pi}{3ZR_{\circ}^{2}}\left(\frac{B(E2)\uparrow e^{2}b^{2}}{e^{2}}\right)^{1/2} \qquad ...(2.53)$$

$$R_{\circ} = 1.2\, A^{1/3}\ \text{fm}$$

$$R_{\circ}^{2} = 0.0144\, A^{2/3}\ \text{barn} \qquad ...(2.54)$$

The single-particle deformation parameter is to be [47] :

$$\beta_{S.p} = \frac{1.59}{Z} \qquad ...(2.55)$$

Where Z is the atomic number.

2-6 Calculation of *B*(*E2*) Values by Experimental Method and Theoretical Predications

2-6-1 Experimental Method

B(*E2*)↑ values can be extracted from a level life time τ measurements which are mutually related to [7] :

$$\tau = 40.81\times10^{13} E_{\gamma}^{-5}\left[\frac{B(E2)\uparrow}{e^{2}b^{2}}\right]^{-1}(1+\alpha_{tot})^{-1} \qquad ...(2.56)$$

Where E_γ and α_{tot} are the γ-ray energy in KeV and the total conversion coefficient, respectively.

2-6-2 Global Best Fit (GBF)

According to the global systematic, a knowledge of the energy *E* (KeV) of the 2^+ state is all that is required to make a prediction for the corresponding τ_γ (Ps) and hence *B*(*E2*)↑ e^2b^2 value [22]. Boher and Mottelson [48,49,50] have derived simple expression for the τ_γ values as follows :

$$\tau_{\gamma} = 0.6 \times 10^{14} E^{-4} Z^{-2} A^{1/3} \qquad ...(2.57)$$

Using equations (2.56, 2.53) the corresponding $B(E2)\uparrow$ and β predictions are given by [22] :

$$B(E2)\uparrow = (2.57 \pm 0.45) E^{-1} Z^{2} A^{-2/3} \qquad ...(2.58)$$

$$\beta = (466 \pm 41) E^{-1/2} A^{-1} \qquad ...(2.59)$$

Even though, the absolute global best fit $B(E2)\uparrow$ predication differs from some measured values, a simple renormalization often brings the predictions in better agreement with the measurements. The "global best fit " values are taken from eq.(2.58) [22] .

2-6-3 Theoretical Predictions

1- Single Shell Asymptotic Nilsson Model (SSANM) :

One of the simplest theoretical models for understanding the $B(E2)\uparrow$ is the SSANM, which is based on "A nucleus is as deformed as it can be in a single shell". This model has been discussed at some previous papers [51,52,53] where the $B(E2)\uparrow$ values (in units of e^2b^2) are given by :

$$B(E2)\uparrow = \frac{5}{16\pi}\left[e^{2} Q_{\circ}\right]^{2} \qquad (Q_{\circ} \neq 0) \qquad ...(2.60)$$

Where $Q_{\circ}$ is the intrinsic quadrupole moment.

2- Finite-Range Droplet Model (FRDM) :

In the FRDM [54] the nuclear ground-state shapes are calculated by minimizing the nuclear potential energy function with respect to ε_2, ε_3, ε_4 and ε_6 shape degree of freedom. More details about this model are in refs.[55,56] .

CHAPTER THREE

RESULTS, DISCUSSION AND CONCLUSIONS

Chapter Three
Results, Discussion and Conclusions

3-1 Results and Calculations

Electromagnetic properties for many even-even nuclei in ${}_{46}$Pd, ${}_{48}$Cd, ${}_{50}$Sn, are studied in present work through :

3-1-1 Calculation of Transition Strength $|M(E2)|^2_{\text{W.u}} \downarrow$

The electric quadrupole transition strengths $|M(E2)|^2_{\text{W.u}} \downarrow$ for γ_0-transition from first excited 2_1^+ state to the 0_1^+ ground state are calculated as a function of neutron number (N) with aid of experimental data reported in ref.[8].

The results of the calculation to $|M(E2)|^2_{\text{W.u}} \downarrow$ are tabulated in tables (3-1, 3-2, and 3-3) for ${}_{50}$Sn, ${}_{48}$Cd and ${}_{46}$Pd respectively.

These tables can be described as follows :

1- The mass number A, neutron number N, with initial level energy E_i, γ_0-transitions energy E_{γ_0} and half-life times $t_{1/2}$ of the initial state are presented in columns 1, 2, 3, 4 and 5, respectively from each table.

2- Mean life times τ for 2_1^+ state whose half-life times $t_{1/2}$ for it reported in ref.[8] calculated by the relation (2.11) and presented in column 6.

3- Total gamma widths Γ_γ calculated by eq.(2.31) presented together with partial gamma widths in W.u calculated by eq.(2.37) in columns 7, 8 respectively.

The partial γ-width $\Gamma(E2)$ for γ-transition is calculated as follows :

According to the electromagnetic γ-transition selection rules for parity and total angular momentum eqs.(1.1, 1.2, and 1.3) there is only one transition for gamma from $j^{\pi} = 2^+$ state to $j^{\pi} = 0^+$ is γ_0 with intensity (100%) *E2* for each even isotope under consideration.

According to eq.(2.34) the values of gamma width Γ_γ listed in column 7 can be considered pure Γ_γ $(E2)_{exp}$ values for γ_0-transitions.

4- The electric quadrupole transition strength $|M(E2)|^2{}_{W.u}\downarrow$ for each γ_0-transitions can be calculated by dividing the partial width Γ_γ $(E2)_{exp}$ obtained in step 3 by the corresponding partial gamma width in W.u Γ_γ $(E2)_{W.u}$, eq.(2.35) was used and the values were presented in column 9.

3-1-2 Calculation of Reduced Transition Probabilities *B*(*E2*)

The results of the calculation to $B(E2)_{W.u}\downarrow$ are tabulated in tables (3-4, 3-5, and 3-6) for $_{50}$Sn, $_{48}$Cd and $_{46}$Pd respectively.

These tables can be described as follows :

1- The total internal conversion coefficients calculated by eq.(2.50) and presented in column 6, where the values of partial coefficients each of which corresponds to the particular atomic shell of the emitted electron (*K*, *L*, *M*.....) are taken from ref.[57].

2- The half-life times for gamma transitions $t_{1/2}$ (γ) $(E2)_{exp}$ were extracted from relation (2.14) and presented in column 7.

3- The half-life times for gamma transitions $t_{1/2}$ (γ) ($E2$) in W.u were calculated by eq.(2.18) and presented in column 8.

4- The reduced transition probabilities $B(E2)\downarrow$ in W.u were calculated from eq.(2.44) and presented in column 9.

It is clear from tables (3-1, 3-2, 3-3) and (3-4, 3-5, 3-6) that the present results to the $|M(E2)|^2{}_{W.u}\downarrow$ values are in excellent agreement with present $B(E2)_{W.u}\downarrow$ values for all even isotopes of $_{50}$Sn, $_{48}$Cd and $_{46}$Pd nuclei.

To get results of precise, the adopted values for $|M(E2)|^2_{W.u} \downarrow$ and $B(E2)_{W.u} \downarrow$ were calculated as adopted $B(E2)_{W.u} \downarrow$ and listed in column 6 from tables (3-7, 3-8, and 3-9).

In order to get good information about the nuclei under the consideration, the adopted values plotted as a function for neutron number N as in figs.(3-1, 3-2, and 3-3) to $_{50}Sn$, $_{48}Cd$ and $_{46}Pd$ respectively.

For the sake of comparison with the experimental values of $B(E2) \uparrow e^2b^2$ for others as well as with others various theoretical models, the present values for the adopted $B(E2)_{W.u} \downarrow$ were converted to $B(E2)_{exp}\uparrow\ e^2b^2$ by using eq.(2.5) and then eq.(2.49), each of $B(E2)_{exp}\downarrow\ e^2b^2$ and $B(E2)_{exp}\uparrow\ e^2b^2$ listed in column 8 and 9 of tables (3-7, 3-8, and 3-9) for $_{50}Sn$, $_{48}Cd$ and $_{46}Pd$ respectively, while $B(E2)_{S.p}\downarrow\ e^2b^2$ was calculated from eq.(2.7).
The comparison presented in tables (3-10, 3-11, and 3-12) and plotted as a function for neutron number N in figs.(3-4, 3-5, and 3-6) for $_{50}Sn$, $_{48}Cd$ and $_{46}Pd$ respectively.

3-1-3 Calculation of Deformation Parameter β

Deformation parameter for even-even $_{50}Sn$, $_{48}Cd$ and $_{46}Pd$ nuclei was extracted from relation (2.53) presented in column 5 of tables (3-13, 3-14, and 3-15) respectively, the $B(E2)_{exp}\uparrow\ e^2b^2$ values which were obtained in sec.(3-1-2) were used, and the values of nucleus radius obtained from eq.(2.54) were presented in column 3 of the same tables, also the calculated β values of γ_0-transitions for $_{50}Sn$, $_{48}Cd$ and $_{46}Pd$ nuclei are compared with the experimental values of ref.[22] which were presented in column 6 of the same tables.

Table (3-1): Transition strengths $|M(E2)|^2_{\text{W.u}} \downarrow$ of γ_0-transitions from $2_1^+ \rightarrow 0_1^+$, total gamma widths $\Gamma_{\gamma\ \exp}(E2)$, partial gamma widths in W.u. $\Gamma_\gamma\ (E2)_{\text{W.u}}$ mean life times τ for the first excited state of $_{50}$Sn. The experimental data of ref.[8] are used in the calculations.

Experimental values of ref.[8]					τ (Ps)	$\Gamma_{\gamma\ \exp}\ (E2) \times 10^{-9}$ (eV)	$\Gamma_\gamma\ (E2)_{\text{W.u}}$ $\times 10^{-9}$ (eV)	$\lvert M(E2)\rvert^2_{W.u.} \downarrow$
A	N	E_i (keV)	E_{γ_0} (keV)	$t_{1/2}$ (Ps)				
112	62	1256.85	1257.05	0.37 ± 0.02	0.53391± 0.028860	1200000 ± 66639	81181	15.1862 ± 0.8209
114	64	1299.92	1299.900	0.30 ± 0.06	0.43290± 0.086580	1500000 ± 304100	98286	15.4701 ± 3.0940
116	66	1293.560	1293.558	0.374 ± 0.010	0.53968± 0.014430	1200000 ± 32611	98161	12.4249 ± 0.3322
118	68	1229.666	1229.68	0.485 ± 0.019	0.69986± 0.027417	940510 ± 36845	77959	12.0641 ± 0.4726
120	70	1171.34	1171.3	0.642 ± 0.010	0.92641± 0.014430	710510 ± 11067	62515	11.3655 ± 0.1770
122	72	1140.55	1140.55	0.76 ± 0.04	1.0967 ± 0.057720	600190 ± 31589	55948	10.7277 ± 0.5646
124	74	1131.739	1131.69	0.92 ± 0.03	1.3276 ± 0.043290	495810 ± 16168	54988	9.0168 ± 0.2940

Table (3-2): Transition strengths $|M(E2)|^2_{\mathrm{W.u}} \downarrow$ of γ_0-transitions from $2_1^+ \to 0_1^+$, total gamma widths $\Gamma_{\gamma\ \mathrm{exp}}(E2)$, partial gamma widths in W.u. $\Gamma_\gamma\ (E2)_{\mathrm{W.u}}$ mean life times τ for the first excited state of $_{48}$Cd. The experimental data of ref.[8] are used in the calculations.

Experimental values of ref.[8]					τ (Ps)	$\Gamma_{\gamma\ \mathrm{exp}}\ (E2) \times 10^{-9}$ (eV)	$\Gamma_\gamma\ (E2)_{\mathrm{W.u}}$ $\times 10^{-9}$ (eV)	$\lvert M(E2)\rvert^2_{W.u.} \downarrow$
A	N	E_i (keV)	E_{γ_0} (keV)	$t_{1/2}$ (Ps)				
106	58	632.64	632.66	7.27 ± 0.09	10.491 ± 0.12987	62744 ± 776.74	2435.9	25.7579 ± 0.3189
108	60	632.986	632.97	6.86 ± 0.07	9.8990 ± 0.10101	66494 ± 678.51	2503.5	26.5604 ± 0.2710
110	62	657.7638	657.7622	5.39 ± 0.07	7.7778 ± 0.10101	84628 ± 1099.1	3108.9	27.2217 ± 0.3535
112	64	617.520	617.516	6.51 ± 0.06	9.3939 ± 0.086580	70069 ± 645.79	2322.4	30.1712 ± 0.2781
114	66	558.456	558.456	10.2 ± 0.6	14.719 ± 0.86580	44720 ± 2630.6	1438.4	31.0900 ± 1.8288
116	68	513.490	513.50	14.1 ± 0.5	20.346 ± 0.72150	32351 ± 1147.2	967.64	33.4328 ± 1.1856
118	70	487.77	487.77	17.9 ± 1.5	25.830 ± 2.1645	25483 ± 2135.5	765.57	33.2865 ± 2.7894

Table (3-3): Transition strengths $|M(E2)|^2_{W.u} \downarrow$ of γ_0-transitions from $2_1^+ \rightarrow 0_1^+$, total gamma widths $\Gamma_{\gamma\ exp}(E2)$, partial gamma widths in W.u. $\Gamma_\gamma (E2)_{W.u}$ mean life time τ for the first excited state of $_{46}Pd$. The experimental data of ref.[8] are used in the calculations.

Experimental values of ref.[8]					τ (Ps)	$\Gamma_{\gamma\ exp}(E2) \times 10^{-9}$ (eV)	$\Gamma_\gamma (E2)_{W.u} \times 10^{-9}$ (eV)	$\lvert M(E2)\rvert^2_{W.u.} \downarrow$
A	N	E_i (keV)	E_{γ_0} (keV)	$t_{1/2}$ (Ps)				
102	56	556.43	556.41	11.5 ± 0.8	16.595 ± 1.1544	39665 ± 2759.3	1217.6	32.5761 ± 2.2662
104	58	555.81	555.796	9.9 ± 0.5	14.286 ± 0.72150	46075 ± 2327.0	1242.7	37.0779 ± 1.8726
106	60	511.851	511.842	12.1 ± 0.3	17.460 ± 0.43290	37698 ± 934.66	844.28	44.6511 ± 1.1071
108	62	433.938	433.937	23.9 ± 0.7	34.488 ± 1.0101	19086 ± 558.99	379.11	50.3434 ± 1.4745
110	64	373.81	373.80	43 ± 3	62.049 ± 4.3290	10608 ± 740.10	184.27	57.5683 ± 4.0164
112	66	348.79	348.70	84 ± 14	121.21 ± 20.202	5430.3 ± 905.05	133.34	40.7264 ± 6.7877
114	68	332.50	332.5	200 ± 60	288.60 ± 86.580	2280.7 ± 684.22	107.62	21.1923 ± 6.3577
116	70	340.6	340.5	110 ± 30	158.73 ± 43.290	4146.8 ± 1130.9	124.05	33.4285 ± 9.1169

Table (3-4): Reduced transition probabilities $B(E2)_{W.u}\downarrow$ of γ_0-transitions from $2_1^+ \rightarrow 0_1^+$ in $_{50}$Sn with internal conversion coefficients $\alpha_{tot}(E2)$ of ref.[57] and half-life times of gamma transitions.

Experimental values of ref.[8]					$\alpha_{tot}(E2) \times 10^{-4}$ ref.[57]	$t_{1/2}(\gamma)(E2)_{exp}$ (Ps)	$t_{1/2}(\gamma)$ $(E2)_{W.u}$ (Ps)	$B(E2)_{W.u}\downarrow$
A	N	E_i (keV)	E_{γ_0} (keV)	$t_{1/2}$ (Ps)				
112	62	1256.85	1257.05	0.37 ± 0.02	6.9 ± 0.3	0.37026 ± 0.020014	5.6201	15.1790 ± 0.8205
114	64	1299.92	1299.900	0.30 ± 0.06	6.4 ± 0.3	0.30019 ± 0.060038	4.6420	15.4635 ± 3.0927
116	66	1293.560	1293.558	0.374 ± 0.010	6.5 ± 0.3	0.37424 ± 0.010007	4.6479	12.4195 ± 0.3321
118	68	1229.666	1229.68	0.485 ± 0.019	7.4 ± 0.3	0.48536 ± 0.019014	5.8523	12.0577 ± 0.4724
120	70	1171.34	1171.3	0.642 ± 0.010	7.9 ± 0.3	0.64251 ± 0.010008	7.2982	11.3589 ± 0.1769
122	72	1140.55	1140.55	0.76 ± 0.04	9.4 ± 0.4	0.76071 ± 0.040038	8.1548	10.7199 ± 0.5642
124	74	1131.739	1131.69	0.92 ± 0.03	9.5 ± 0.4	0.92087 ± 0.030029	8.2972	9.0101 ± 0.2938

Table (3-5): Reduced transition probabilities $B(E2)_{W.u}\downarrow$ of γ_0-transitions from $2_1^+ \rightarrow 0_1^+$ in $_{48}$Cd with internal conversion coefficients $\alpha_{tot}(E2)$ of ref.[57] and half-life times of gamma transitions.

Experimental values of ref.[8]					$\alpha_{tot}(E2) \times 10^{-4}$ ref.[57]	$t_{1/2}(\gamma)(E2)_{exp}$ (Ps)	$t_{1/2}(\gamma)$ $(E2)_{W.u}$ (Ps)	$B(E2)_{W.u}\downarrow$
A	N	E_i (keV)	E_{γ_0} (keV)	$t_{1/2}$ (Ps)				
106	58	632.64	632.66	7.27 ± 0.09	33.9 ± 0.9	7.2946 ± 0.090307	187.30	25.6763 ± 0.3179
108	60	632.986	632.97	6.86 ± 0.07	33.9 ± 0.9	6.8833 ± 0.070240	182.24	26.4762 ± 0.2702
110	62	657.7638	657.7622	5.39 ± 0.07	30.6 ± 0.9	5.4065 ± 0.070216	146.76	27.1443 ± 0.3525
112	64	617.520	617.516	6.51 ± 0.06	36.2 ± 1.0	6.5336 ± 0.060221	196.46	30.0687 ± 0.2771
114	66	558.456	558.456	10.2 ± 0.6	47.5 ± 1.3	10.248 ± 0.060300	317.18	30.9495 ± 0.1821
116	68	513.490	513.50	14.1 ± 0.5	60.1 ± 1.6	14.185 ± 0.50301	471.50	33.2401 ± 1.1787
118	70	487.77	487.77	17.9 ± 1.5	71.2 ± 1.9	18.027 ± 1.5107	595.95	33.0581 ± 2.7702

Table (3-6): Reduced transition probabilities $B(E2)_{W.u}\downarrow$ of γ_0-transitions from $2_1^+ \rightarrow 0_1^+$ in $_{46}$Pd with internal conversion coefficients α_{tot} $(E2)$ of ref.[57] and half-life times of gamma transitions.

Experimental values of ref.[8]					α_{tot} $(E2) \times 10^{-4}$ ref.[57]	$t_{1/2}$ (γ) $(E2)_{exp}$ (Ps)	$t_{1/2}$ (γ) $(E2)_{W.u}$ (Ps)	$B(E2)_{W.u}\downarrow$
A	N	E_i (keV)	E_{γ_0} (keV)	$t_{1/2}$ (Ps)				
102	56	556.43	556.41	11.5 ± 0.8	43.1 ± 1.2	11.550 ± 0.80345	374.70	32.4431 ± 2.2569
104	58	555.81	555.796	9.9 ± 0.5	43.2 ± 1.2	9.9428 ± 0.50216	367.15	36.9262 ± 1.8650
106	60	511.851	511.842	12.1 ± 0.3	54.5 ± 1.5	12.166 ± 0.30164	540.39	44.4184 ± 1.1013
108	62	433.938	433.937	23.9 ± 0.7	90.9 ± 2.4	24.117 ± 0.70639	1203.5	49.9004 ± 1.4616
110	64	373.81	373.80	43 ± 3	145 ± 4	43.623 ± 3.0435	2476.0	56.7574 ± 3.9599
112	66	348.79	348.70	84 ± 14	180 ± 5	85.512 ± 14.252	3421.7	40.0147 ± 6.6691
114	68	332.50	332.5	200 ± 60	120 ± 6	202.40 ± 60.720	4239.3	20.9454 ± 6.2836
116	70	340.6	340.5	110 ± 30	195 ± 5	112.15 ± 30.585	3677.9	32.7960 ± 8.9444

Table (3-7): The adopted values for $B(E2;\, 2_1^+ \rightarrow 0_1^+)_{\mathrm{W.u.}} \downarrow$ and $B(E2)_{exp}\uparrow$ e^2b^2 for γ_0-transitions in ${}_{50}$Sn nuclides.

Experimental values of ref.[8]			$\lvert M(E2)\rvert^2_{W.u.} \downarrow$	$B(E2)_{\mathrm{W.u.}}\downarrow$	Adopted $B(E2)_{\mathrm{W.u.}}\downarrow$	$B(E2)_{\mathrm{S.p}}\downarrow$ (e^2b^2)	$B(E2)_{exp}\downarrow$ (e^2b^2)	$B(E2)_{exp}\uparrow$ (e^2b^2)
A	N	E_{γ_0} (keV)						
112	62	1257.05	15.1862 ± 0.8209	15.1790 ± 0.8205	15.1826 ± 0.5803	0.0032	0.0487 ± 0.0019	0.2434 ± 0.0093
114	64	1299.900	15.4701 ± 3.0940	15.4635 ± 3.0927	15.4668 ± 2.1873	0.0033	0.0508 ± 0.0072	0.2539 ± 0.0359
116	66	1293.558	12.4249 ± 0.3322	12.4195 ± 0.3321	12.4222 ± 0.2349	0.0034	0.0417±0.00078937	0.2087 ± 0.0039
118	68	1229.68	12.0641 ± 0.4726	12.0577 ± 0.4724	12.0609 ± 0.3341	0.0034	0.0415 ± 0.0011	0.2073 ± 0.0057
120	70	1171.3	11.3655 ± 0.1770	11.3589 ± 0.1769	11.3622 ± 0.1251	0.0035	0.0399±0.00043983	0.1997 ± 0.0022
122	72	1140.55	10.7277 ± 0.5646	10.7199 ± 0.5642	10.7238 ± 0.3991	0.0036	0.0385 ± 0.0014	0.1927 ± 0.0072
124	74	1131.69	9.0168 ± 0.2940	9.0101 ± 0.2938	9.0134 ± 0.2078	0.0037	0.0331±0.00076324	0.1655 ± 0.0038

Table (3-8): The adopted values for $B(E2;\, 2_1^+ \rightarrow 0_1^+)_{W.u.} \downarrow$ and $B(E2)_{exp} \uparrow$ e^2b^2 for γ_0-transitions in $_{48}$Cd nuclides.

Experimental values of ref.[8]			$\|M(E2)\|^2_{W.u.} \downarrow$	$B(E2)_{W.u.} \downarrow$	Adopted $B(E2)_{W.u.} \downarrow$	$B(E2)_{S.p.} \downarrow$ (e^2b^2)	$B(E2)_{exp} \downarrow$ (e^2b^2)	$B(E2)_{exp} \uparrow$ (e^2b^2)
A	N	E_{γ_0} (keV)						
106	58	632.66	25.7579 ± 0.3189	25.6763 ± 0.3179	25.7170 ± 0.2251	0.0030	0.0766±0.00067076	0.3832 ± 0.0034
108	60	632.97	26.5604 ± 0.2710	26.4762 ± 0.2702	26.5182 ± 0.1913	0.0031	0.0810±0.00058443	0.4051 ± 0.0029
110	62	657.7622	27.2217 ± 0.3535	27.1443 ± 0.3525	27.1829 ± 0.2496	0.0031	0.0851±0.00078143	0.4255 ± 0.0039
112	64	617.516	30.1712 ± 0.2781	30.0687 ± 0.2771	30.1198 ± 0.1963	0.0032	0.0966±0.00062950	0.4829 ± 0.0031
114	66	558.456	31.0900 ± 1.8288	30.9495 ± 0.1821	30.9509 ± 0.1812	0.0033	0.1016±0.00059496	0.5081 ± 0.0030
116	68	513.50	33.4328 ± 1.1856	33.2401 ± 1.1787	33.3359 ± 0.8359	0.0034	0.1120 ± 0.0028	0.5601 ± 0.0140
118	70	487.77	33.2865 ± 2.7894	33.0581 ± 2.7702	33.1715 ± 1.9656	0.0034	0.1140 ± 0.0068	0.5702 ± 0.0338

Table (3-9): The adopted values for $B(E2;\, 2_1^+ \rightarrow 0_1^+)_{\mathrm{W.u}} \downarrow$ and $B(E2)_{exp}\uparrow$ e^2b^2 for γ_0-transitions in $_{46}$Pd nuclides.

Experimental values of ref.[8]			$\lvert M(E2)\rvert^2_{W.u.}\downarrow$	$B(E2)_{W.u}\downarrow$	Adopted $B(E2)_{W.u}\downarrow$	$B(E2)_{S.p}\downarrow$ (e^2b^2)	$B(E2)_{exp}\downarrow$ (e^2b^2)	$B(E2)_{exp}\uparrow$ (e^2b^2)
A	N	E_{γ_0} (keV)						
102	56	556.41	32.5761 ± 2.2662	32.4431 ± 2.2569	32.5093 ± 1.5991	0.0028	0.0920 ± 0.0045	0.4601 ± 0.0226
104	58	555.796	37.0779 ± 1.8726	36.9262 ± 1.8650	37.0017 ± 1.3214	0.0029	0.1075 ± 0.0038	0.5375 ± 0.0192
106	60	511.842	44.6511 ± 1.1071	44.4184 ± 1.1013	44.5341 ± 0.7808	0.0030	0.1327 ± 0.0023	0.6635 ± 0.0116
108	62	433.937	50.3434 ± 1.4745	49.9004 ± 1.4616	50.1200 ± 1.0380	0.0031	0.1531 ± 0.0032	0.7656 ± 0.0159
110	64	373.80	57.5683 ± 4.0164	56.7574 ± 3.9599	57.1571 ± 2.8198	0.0031	0.1789 ± 0.0088	0.8947 ± 0.0441
112	66	348.70	40.7264 ± 6.7877	40.0147 ± 6.6691	40.3643 ± 4.7571	0.0032	0.1294 ± 0.0153	0.6472 ± 0.0763
114	68	332.5	21.1923 ± 6.3577	20.9454 ± 6.2836	21.0674 ± 4.4691	0.0033	0.0692 ± 0.0147	0.3459 ± 0.0734
116	70	340.5	33.4285 ± 9.1169	32.7960 ± 8.9444	33.1062 ± 6.3848	0.0034	0.1113 ± 0.0215	0.5563 ± 0.1073

Table (3-10): The calculated reduced transition probabilities $B(E2)$ $e^2b^2 \uparrow$ values are compared with that of experimental and theoretical predications for $_{50}Sn$ nuclides.

A	N	E_{γ_0} (keV)	$B(E2;0_1^+ \rightarrow 2_1^+)$ e^2b^2				
			Experimental values of present work	Experimental values of ref.[22]	Theoretical values ref.[22]		
					Global Best fit	SSANM	FRDM
112	62	1257.05	0.2434 ± 0.0093	0.240 ± 0.014	0.220 ± 0.038	0.407	0.005
114	64	1299.900	0.2539 ± 0.0359	0.24 ± 0.05	0.210 ± 0.037	0.406	< 0.001
116	66	1293.558	0.2087 ± 0.0039	0.209 ± 0.006	0.208 ± 0.036	0.394	< 0.001
118	68	1229.68	0.2073 ± 0.0057	0.209 ± 0.008	0.217 ± 0.038	0.379	< 0.001
120	70	1171.3	0.1997 ± 0.0022	0.2020 ± 0.0040	0.225 ± 0.039	0.365	< 0.001
122	72	1140.55	0.1927 ± 0.0072	0.1920 ± 0.0040	0.229 ± 0.040	0.286	< 0.001
124	74	1131.69	0.1655 ± 0.0038	0.1660 ± 0.0040	0.228 ± 0.040	0.190	< 0.001

Table (3-11): The calculated reduced transition probabilities $B(E2)$ e^{2}b^2 ↑ values are compared with that of experimental and theoretical predications for $_{48}$Cd nuclides.

A	N	E_{γ_0} (keV)	$B(E2;0_1^+ \rightarrow 2_1^+)$ e^{2}b^2				
			Experimental values of present work	Experimental values of ref.[22]	Theoretical values ref.[22]		
					Global Best fit	SSANM	FRDM
106	58	632.66	0.3832 ± 0.0034	0.410 ± 0.020	0.42 ± 0.07	0.478	0.236
108	60	632.97	0.4051 ± 0.0029	0.430 ± 0.020	0.41 ± 0.07	0.577	0.272
110	62	657.7622	0.4255 ± 0.0039	0.450 ± 0.020	0.39 ± 0.07	0.634	0.311
112	64	617.516	0.4829 ± 0.0031	0.510 ± 0.020	0.41 ± 0.07	0.632	0.319
114	66	558.456	0.5081 ± 0.0030	0.545 ± 0.020	0.45 ± 0.08	0.617	0.419
116	68	513.50	0.5601 ± 0.0140	0.560 ± 0.020	0.48 ± 0.08	0.600	0.684
118	70	487.77	0.5702 ± 0.0338	0.568 ± 0.044	0.50 ± 0.09	0.581	0.688

Table (3-12): The calculated reduced transition probabilities $B(E2)$ e^2b^2 ↑ values are compared with that of experimental and theoretical predications for $_{46}Pd$ nuclides.

A	N	E_{γ_0} (keV)	$B(E2;0_1^+ \rightarrow 2_1^+)$ e^2b^2				
			Experimental values of present work	Experimental values of ref.[22]	Theoretical values ref.[22]		
					Global Best fit	SSANM	FRDM
102	56	556.41	0.4601 ± 0.0226	0.460 ± 0.030	0.45 ± 0.08	0.494	0.278
104	58	555.796	0.5375 ± 0.0192	0.535 ± 0.035	0.44 ± 0.08	0.619	0.361
106	60	511.842	0.6635 ± 0.0116	0.660 ± 0.035	0.47 ± 0.08	0.728	0.404
108	62	433.937	0.7656 ± 0.0159	0.760 ± 0.040	0.55 ± 0.10	0.789	0.520
110	64	373.80	0.8947 ± 0.0441	0.870 ± 0.040	0.63 ± 0.11	0.788	0.707
112	66	348.70	0.6472 ± 0.0763	0.66 ± 0.11	0.67 ± 0.12	0.771	0.600
114	68	332.5	0.3459 ± 0.0734	0.38 ± 0.12	0.69 ± 0.12	0.752	0.635
116	70	340.5	0.5563 ± 0.1073	0.62 ± 0.18	0.67 ± 0.12	0.732	0.638

Table (3-13): The values of nucleus radius and deformation parameters compared with that in ref.[22] for γ_0-transitions in $_{50}Sn$ nuclides.

A	N	R_0^2 (b)	$B(E2)_{exp}\uparrow$ (e^2b^2)	β values of present work	β values of ref.[22]
112	62	0.3346	0.2434 ± 0.0093	0.1235 ± 0.0241	0.1226 ± 0.0036
114	64	0.3386	0.2539 ± 0.0359	0.1246 ± 0.0469	0.121 ± 0.013
116	66	0.3425	0.2087 ± 0.0039	0.1117 ± 0.0153	0.1118 ± 0.0016
118	68	0.3464	0.2073 ± 0.0057	0.1100 ± 0.0182	0.1105 ± 0.0021
120	70	0.3503	0.1997 ± 0.0022	0.1068 ± 0.0112	0.1075 ± 0.0011
122	72	0.3542	0.1927 ± 0.0072	0.1038 ± 0.0201	0.1036 ± 0.0011
124	74	0.3581	0.1655 ± 0.0038	0.0951 ± 0.0144	0.0953 ± 0.0011

Table (3-14): The values of nucleus radius and deformation parameters compared with that in ref.[22] for γ_0-transitions in $_{48}Cd$ nuclides.

A	N	R_0^2 (b)	$B(E2)_{exp}\uparrow$ (e^2b^2)	β values of present work	β values of ref.[22]
106	58	0.3225	0.3832 ± 0.0034	0.1674 ± 0.0158	0.1732 ± 0.0042
108	60	0.3266	0.4051 ± 0.0029	0.1700 ± 0.0144	0.1752 ± 0.0041
110	62	0.3306	0.4255 ± 0.0039	0.1721 ± 0.0165	0.1770 ± 0.0039
112	64	0.3346	0.4829 ± 0.0031	0.1812 ± 0.0145	0.1862 ± 0.0037
114	66	0.3386	0.5081 ± 0.0030	0.1836 ± 0.0141	0.1903 ± 0.0035
116	68	0.3425	0.5601 ± 0.0140	0.1906 ± 0.0301	0.1906 ± 0.0034
118	70	0.3464	0.5702 ± 0.0338	0.1901 ± 0.0463	0.190 ± 0.007

Table (3-15): The values of nucleus radius and deformation parameters compared with that in ref.[22] for γ_0-transitions in $_{46}Pd$ nuclides.

A	N	R_0^2 (b)	$B(E2)_{exp}\uparrow$ (e^2b^2)	β values of present work	β values of ref.[22]
102	56	0.3144	0.4601± 0.0226	0.1964± 0.0435	0.196± 0.006
104	58	0.3185	0.5375±0.0192	0.2095±0.0396	0.209±0.007
106	60	0.3225	0.6635±0.0116	0.2299±0.0304	0.229±0.006
108	62	0.3266	0.7656±0.0159	0.2439±0.0351	0.243±0.006
110	64	0.3306	0.8947±0.0441	0.2604±0.0578	0.257±0.006
112	66	0.3346	0.6472±0.0763	0.2188±0.0751	0.220±0.018
114	68	0.3386	0.3459±0.0734	0.1581±0.0728	0.164±0.027
116	70	0.3425	0.5563±0.1073	0.1982±0.0870	0.207±0.031

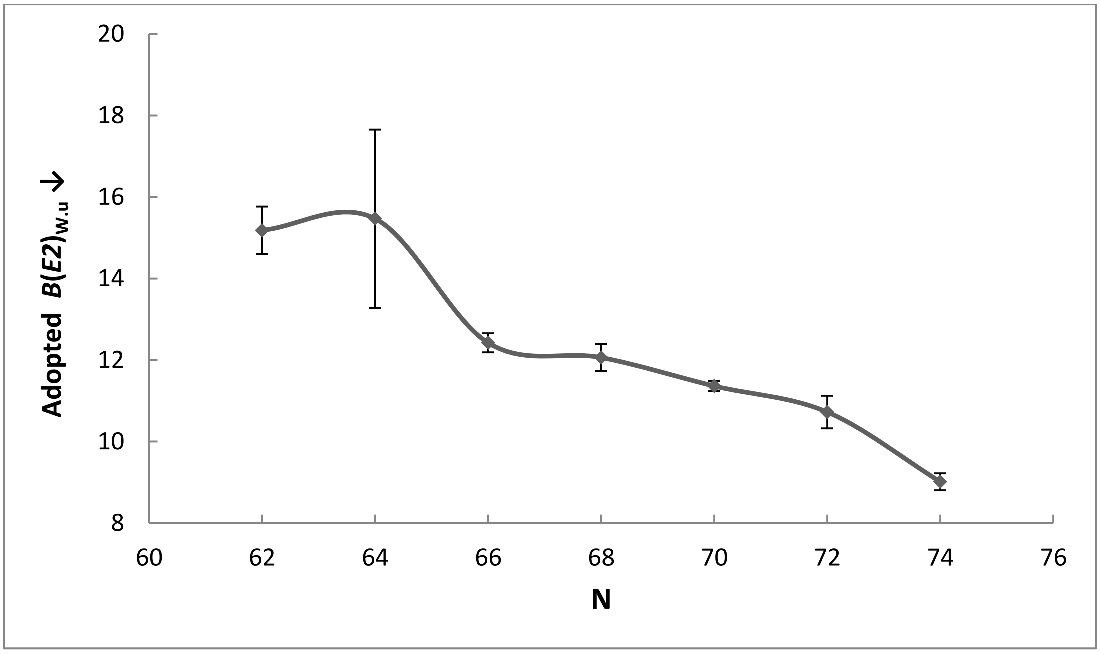

Figure (3-1): The adopted values of $B(E2)_{W.u}\downarrow$ for γ_0-transition as a function of neutron number (N) in $_{50}$Sn nuclides.

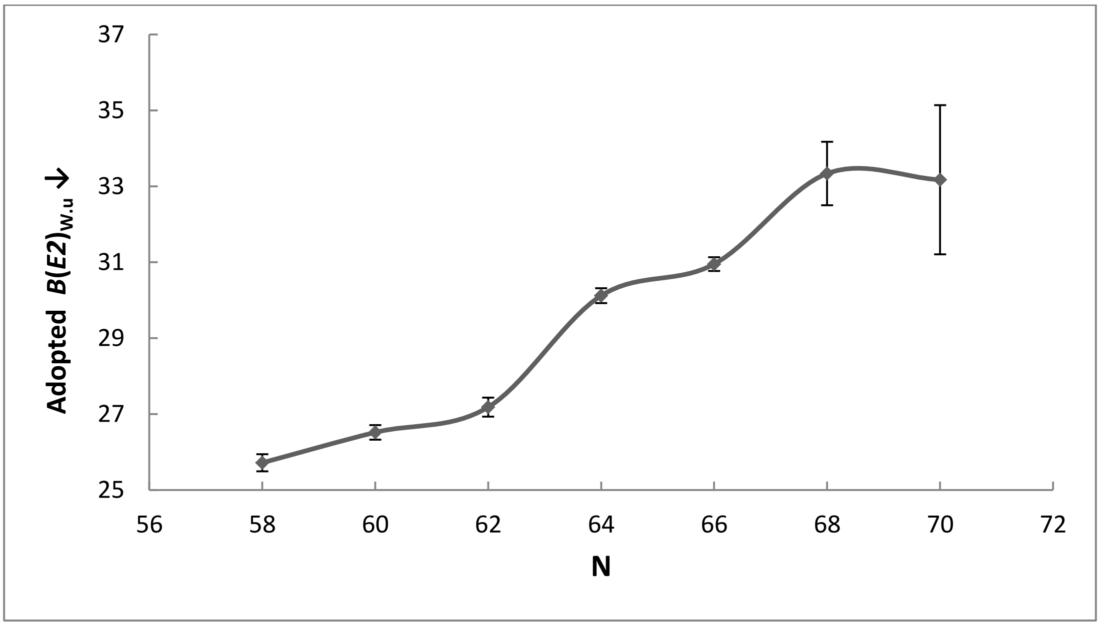

Figure (3-2): The adopted values of $B(E2)_{W.u}\downarrow$ for γ_0-transition as a function of neutron number (N) in $_{48}$Cd nuclides.

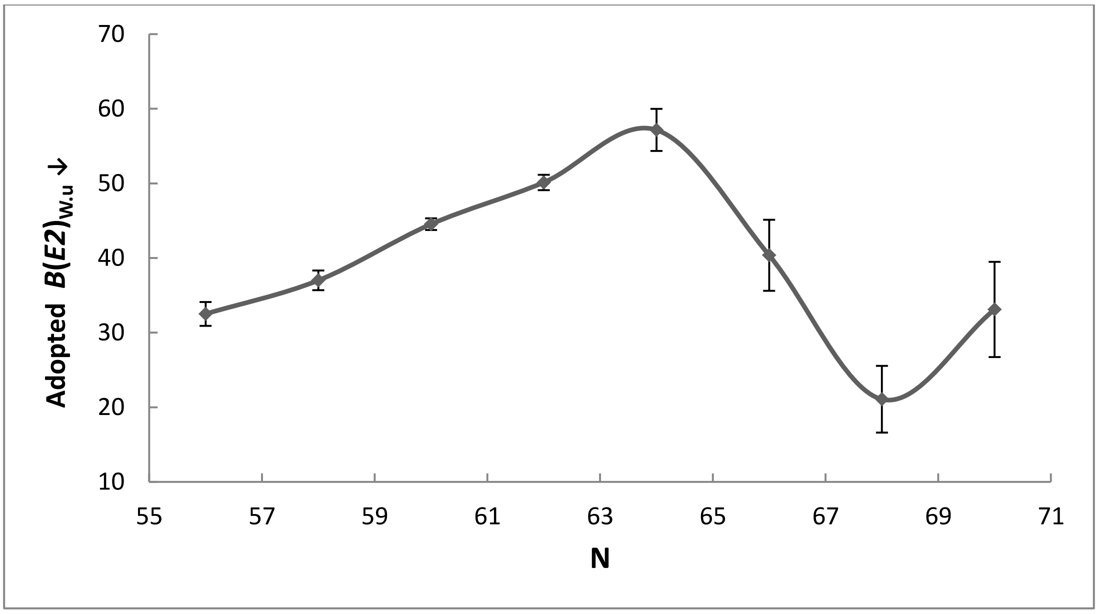

Figure (3-3): The adopted values of $B(E2)_{\mathrm{W.u}}\downarrow$ for γ_0-transition as a function of neutron number (N) in $_{46}$Pd nuclides.

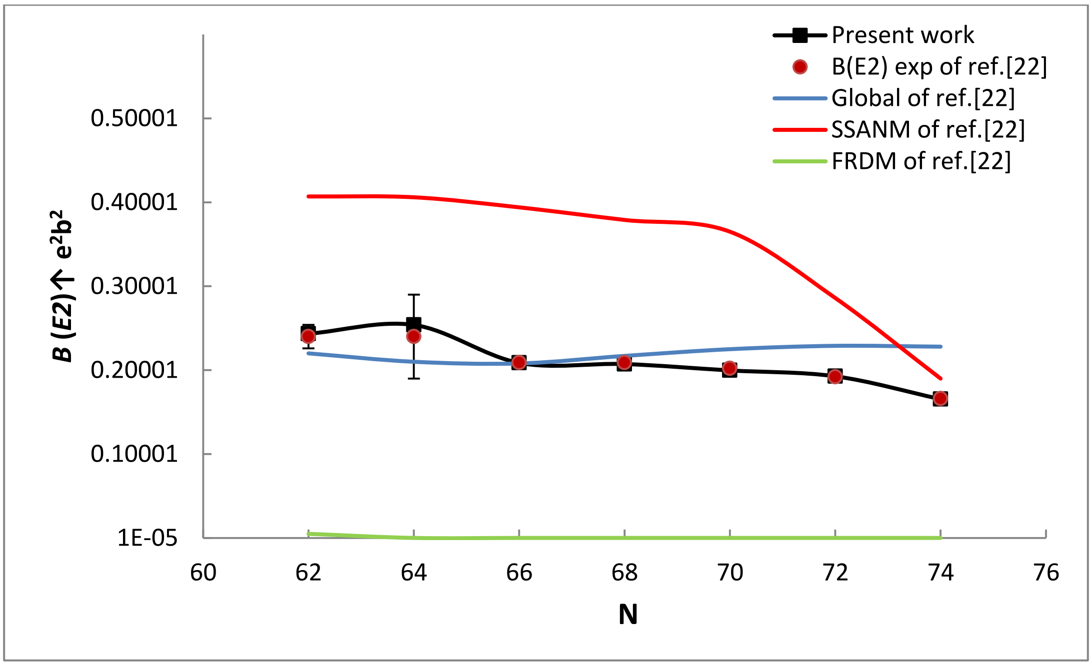

Figure (3-4): Comparison between the $B(E2)\uparrow e^2b^2$ values of the present work for $_{50}$Sn nuclides with experimental and other theoretical results.

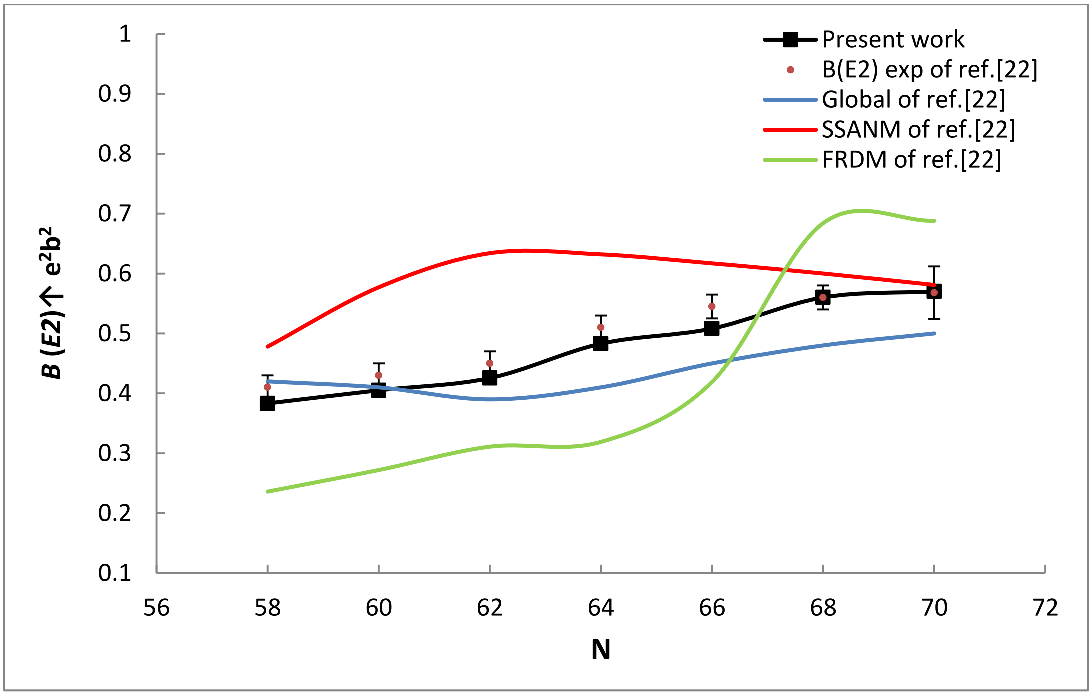

Figure (3-5): Comparison between the $B(E2) \uparrow e^2b^2$ values of the present work for $_{48}$Cd nuclides with experimental and other theoretical results.

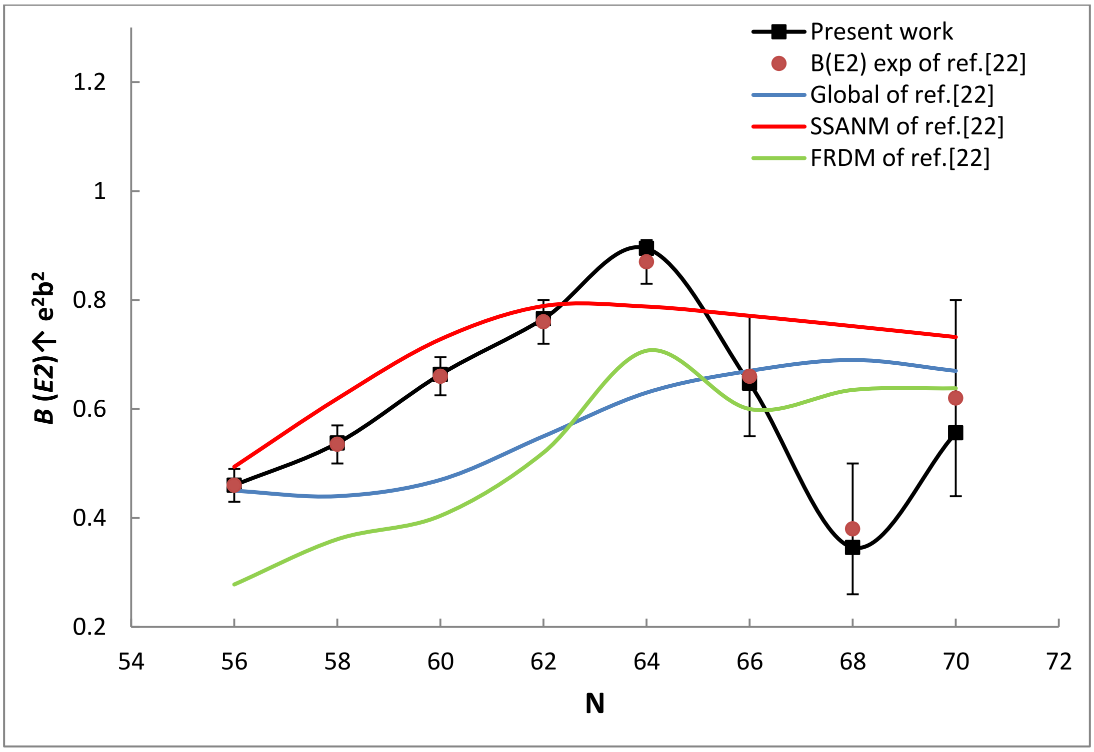

Figure (3-6): Comparison between the $B(E2) \uparrow e^2b^2$ values of the present work for $_{46}$Pd nuclides with experimental and other theoretical results.

3-2 Discussion and Conclusion

The variety of different shapes for nuclei have been observed and / or predicated that depends on the neutron to proton ratio and on the conditions of excitation energy or spin of nuclei [58] .

Present work focused on effect of the excitation energy and reduced transition probabilities $B(E2;\ 2_1^+ \rightarrow 0_1^+)$ versus the neutron number in isotonic chains on the variation of the nucleus shapes, because the quadrupole deformation parameter β extracted from the reduced transition probability $B(E2)_{exp} \uparrow e^2b^2$.

The best results which we obtained from 2_1^+ excited state in rich neutron nuclei, such as $_{50}$Sn, $_{48}$Cd and $_{46}$Pd helped us in predicting the nuclei shape, this can be explained in the following articles.

3-2-1 Isotopes of Tin

Magic nuclei have very few excited states at low excitation energy, their low transition probabilities include low collective motion for nucleons and indicate the validity of single shell model [58].

Fig.(3-4) shows the reduced transition probability $B(E2) \uparrow e^2b^2$ as a function of neutron number in isotonic chain ranging between 62 and 74 for Sn nucleus have the magic atomic number Z = 50.

The $B(E2) \uparrow e^2b^2$ values for ^{112}Sn is 0.243(9) e^2b^2 and for ^{114}Sn is 0.254(36) e^2b^2 which confirms larger $B(E2) \uparrow e^2b^2$ value belong to the lighter tin isotopes.

on the neutron rich side of the $_{50}$Sn chain with the range 62→74 there is almost constant plateau with minimum values to $B(E2) \uparrow e^2b^2$ which support the magic nucleus has a large number of stable isotopes.

Also we can observe from table (3-13), the maximum β value is 0.125(47) for ^{114}Sn, while the minimum value is 0.095(14) for ^{124}Sn, from the values of $B(E2) \uparrow e^2b^2$ and β can be concluded that ^{124}Sn isotope which could close the proton and neutron shells is more stable than others tin isotopes.

In general all tin isotopes under the present study are deviated from spherical shape but with a small different percentages.

3-2-2 Isotopes of Cadmium

The values of reduced transition probabilities $B(E2) \uparrow e^2b^2$ to first excited state 2_1^+ in semi-magic nuclei as in magic nuclei are usually correlated with the excitation energy, the low values to $B(E2) \uparrow e^2b^2$ is correlated with the low excitation energy [59].

Let us now come back to the $B(E2) \uparrow e^2b^2$ curve, for isotonic chain with the $58 \le N \le 70$ to the semi-magic nucleus of Z = 48.

The $B(E2) \uparrow e^2b^2$ has not constant plateau as in $_{50}$Sn, where $B(E2) \uparrow e^2b^2$ increased slightly with neutron number increase.

Low transition value for ^{106}Cd with closed shell at N = 58 versus low excitation energy indicated any excitation can overcome the gap [58].

According to this explanation, the deformation parameter β which is extracted from $B(E2) \uparrow e^2b^2$ increases in range between 58 and 70 as in table (3-14) with the minimum value for β is 0.167(6).

From the values of $B(E2) \uparrow e^2b^2$ and β can be concluded that ^{106}Cd isotope is more stable than others and with less deform in shape.

3-2-3 Isotopes of Palladium

Near closed shells spherical shape prevail, while between closed shells there is a large number of nucleons this leads to dominance of collective motion and a variety in shapes can be observed in ground state. If the same nucleus is excited from the ground state to 2_1^+ state, the deformation in shape can be studied through the excitation energy and reduced transition probability $B(E2) \uparrow e^2b^2$.

In present study of palladium nucleus of atomic number 46 between closed shells 40 and 50, with isotonic chain ranging between 70 and 56, the study did through the calculation for $B(E2) \uparrow e^2b^2$ as a function for excited energy versus neutron number as follows :

1- In the range of $56 \leq N \leq 64$ the $B(E2) \uparrow e^2b^2$ values are inversely proportional to the excitation energy of the 2_1^+ state as seen in table (3-9) and suggested in ref.[60]. The *E2* transition strengths hindered via the high excitation energies.

2- The values of $B(E2) \uparrow e^2b^2$ for ^{112,114}Pd were deviated from the values of our expectation and the suggestion of ref.[60] as in table (3-9), special the measured value $B(E2) \uparrow e^2b^2$to ^{114}Pd taken the minimum values in the curve, that goes to the suppressed proton collectivity in ^{112,114}Pd and that points out the dominance of the large neutron collectivity shared the interference between the nuclear and electromagnetic interaction in the excitation from the ground state to the 2_1^+ state [61] which indicated the ^{114}Pd has few excited states even in the comparison with ^{116}Pd of a sub-shell closure at N=70, its $B(E2) \uparrow e^2b^2$ value higher than that for ^{114}Pd.

Since the deformation parameter β relates $B(E2) \uparrow e^2b^2$ directly, so the minimum value is $\beta = 0.158(73)$ for ^{114}Pd.

In general all the values for β to the $_{46}$Pd isotopes under the study are large as in table (3-15), the value of β is 0.260(58) for ^{110}Pd it is too large if it is compared with value 0.3 for the nuclei stable permanent deformation ($150 \leq A \leq 190$) [4].

The low energy of the first excited 2_1^+ state and the large transition probability are in agreement with such a deformed shape.

However the minimum for $B(E2) \uparrow e^2b^2$ in curve of fig (3-6) and β of table (3-15) at N = 68 give predication ^{114}Pd is more stable in isotonic chain to $_{46}$Pd.

3-2-4 Comparison between Experimental and Theoretical Results

The $B(E2) \uparrow e^2b^2$ values are basic experimental quantities that do not depend on nuclear models [22], it is always accurate values calculated with associated errors as tables (3-10, 11, and 12) showed. While the values of $B(E2) \uparrow e^2b^2$ of nuclear models are calculated without associated errors as shown in the same tables, so they are un accurate values.

Thus nuclear models sometimes depend on empirical formula or on terms assumed by theoretical physicists through their studies, that pointed to the nuclear models which often give predicted values.

Our work gave an excellent agreement for the present values of reduced transition probabilities $B(E2) \uparrow e^2b^2$ and deformation parameters β with those of experimental of ref.[22] which provided the most accurate comparisons to theoretical values which are taken from different nuclear models.

3-3 Suggestions and Future Works

We suggest some future works :

1- Study the other isotopes of $_{50}Sn$, $_{48}Cd$ and $_{46}Pd$ that didn't study in this work.

2- Study the other properties of this even-even nuclides depending on current results such as the quadrupole moment (Q).

3- Use the interacting boson model (IBM) to study the excited structure for this even-even nuclides and noticed the effect of this model on the results.

4- Study the even-even or even-odd or odd-odd isotopes for other nucleus.

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الخلاصة

درست الخواص الكهرومغناطيسية للنظائر زوجية - زوجية للنوى $_{50}Sn$, $_{48}Cd$ و $_{46}Pd$ الغنية بالنيوترونات من خلال قوى الأنتقال لرباعي القطب الكهربائي $|M(E2)|^2{}_{W.u}\downarrow$ وأحتمالية الأنتقال المختزل $B(E2)_{W.u}\downarrow$ لأنتقال أشعة كاما من المستوى المتهيج الأول 2_1^+ الى المستوى الأرضي.

حيث تم حساب قوى الأنتقال لرباعي القطب الكهربائي $|M(E2)|^2{}_{W.u}\downarrow$ بالأستعانة بمعدل العمر للمستوى المتهيج الأول والشدة النسبية لأشعة كاما المنبعثة من ذلك المستوى، بينما قيم أحتمالية الأنتقال المختزل $B(E2)_{W.u}\downarrow$ أستخرجت من خلال عمر النصف للمستوى المتهيج الأول 2_1^+ المصحح لمعامل التحول الداخلي.

وللحصول على قيمة دقيقة لأنتقال رباعي القطب الكهربائي $E2\downarrow$ ، تم حساب ورسم القيم المتبناة لكل من $|M(E2)|^2{}_{W.u}\downarrow$ و $B(E2)_{W.u}\downarrow$ كدالة لعدد النيوترونات.

في هذا البحث، تم تحويل القيم المتبناة لأنتقال $E2\downarrow$ الى قيم أحتمالية الأنتقال المختزل $B(E2)\uparrow e^2b^2$ والتي أفادتنا في دراسة تركيب النوى من حيث الاختلاف في الشكل لأن عامل التشوه β تم أستخراجه من $B(E2)\uparrow e^2b^2$، كما أن دراسة تأثير عدد النيوترونات على سلوك كل من $B(E2)\uparrow e^2b^2$ و β في المتسلسلات الايزوتونية لنوى $_{50}Sn$, $_{48}Cd$ و $_{46}Pd$ يعطي معلومات جيدة حول التشوه في النوى.

تركزت دراستنا على ثلاث أنواع مختلفة من النوى، الأول بعدد ذري سحري 50، والثاني بعدد ذري شبه سحري 48، والثالث بعدد ذري بين القشرات المغلقة 46.

في نهاية العمل الحالي تم عمل مقارنة جيدة للحسابات الحالية لقيم أحتمالية الأنتقال المختزل $B(E2)\uparrow e^2b^2$ وعامل التشوه β مع معظم القيم العملية والنظرية الحديثة.

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة بغداد
كلية التربية للعلوم الصرفة / أبن الهيثم

دراسة التركيب المتهيج للنوى زوجية – زوجية ذات العدد الذري Z= 50, 48, 46 في المستوى المتهيج الأول

رسالة مقدمة الى
كلية التربية للعلوم الصرفة / أبن الهيثم – جامعة بغداد
كجزء من متطلبات نيل درجة ماجستير علوم في الفيزياء

من قبل

رسل سعد هادي

بكلوريوس–2012

بأشراف

د. فاطمة عبد الامير جاسم

أستاذ

2015هـ **2015**