Full Length Research Paper

Calculation of 8+ Isomers of even-even Nuclei 76Ni to 94Pd for N = 48 neutrons

H. Y. Abdullah[1,2]*, I. Hossain[1,3], I. M. Ahmed[4], S. T. Ahmad[5], W. Q. Karwan[2], M. K. Kasimin[1], J. C. Chong[1], K. K. Viswanathan[6] and N. Ibrahim[1]

[1]Department of Physics, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia.
[2]Department of Physics, College of Science Education, Salahaddin University, Erbil, Krg, Iraq.
[3]Department of Physics, Shah Jalal University of Science and Technology,Sylhet 3114, Bangladesh.
[4]Department of Physics, College of Education, Mosul University, Mosul, Iraq.
[5]Department of Physics, Faculty of Science and Engineering, Koya University, Koya, Erbil, Iraq.
[6]Department of Mathmatics, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia.

Study of the properties of nuclear isomers is a current research focus. We have studied the systematic 8+ isomeric levels, half-lives, deformation parameters, and reduced transition probabilities between $8^+ \rightarrow 6^+$ state of even-even 76Ni to 94Pd nuclei for N = 48 neutrons. The calculated half-lives and quadrupole moments are compared with the experimental values. Moreover, we have studied the systematic B (E2) values, intrinsic quadrupole moments and values of β/β_{2SP} as a function of atomic number (Z) for N = 48 neutrons.

Key words: Half-life, quadrupole moment, deformation parameter, reduced transition probability.

INTRODUCTION

The nuclear structure studies are at the heart of understanding the formation of nuclear isomers with applications to many aspects in nuclear physics. The study is particularly interesting and important for unstable nuclei, such as those in neutron-rich, proton-rich, and super heavy mass regions. Usually ground state is more stable than the excited states. However, the lifetime of ground state of unstable nuclei is short, which makes the laboratory study extremely difficult (Sun, 2008).

Octupole electric transition in even-even nuclei for N = 48 have recently been of much interest both theoretically and experimentally. From a theoretical point of view, the yrast states up to $I^\pi = 8^+$ in N= 48 isotones can be ascribed to the two-hole states $\nu g_{9/2}^{-2}$ for the N=50 closed shell. Moreover, their 8+ states were confirmed to become an isomer from even-even nuclei 76Ni to 94Pd (Gorska et al., 1995, Mrginean et al., 2003; Chakraborty et al., 2004; Sawicka et al., 2003; Grzywacz, 2005). These isomers occur because of large spin differences in the configuration of the initial and final states or a reduction in transition energies as one approaches the highest spin possible for the given seniority multiplet. However, the details calculation of quadrupole moments, deformation parameter, moment of inertia $\Im$ of the 8+ state of even-even nuclei for N=48 are not been calculated yet. At present, we have reported E2 transitions energy from $8^+ \rightarrow 6^+$, deformation

*Corresponding author. E-mail: kuhewa@yahoo.com. Tel: +6-07-5534088. Fax: +6-07-5566162.

parameter β, existence of correlations between half-lives, reduced transition probabilities, Q_0, and β/β_{2SP} values as a function of atomic number, and other nuclear spectroscopic properties of the N=48 nuclei, ^{76}Ni, ^{78}Zn, ^{80}Ge, ^{82}Se, ^{84}Kr, ^{86}Sr, ^{88}Zr, ^{90}Mo, ^{92}Ru and ^{94}Pd by theoretical investigations.

THEORETICAL SURVEY

Half-life

The low-lying levels of even-even nuclei (J_i =2,4,6,8…….) usually decay by one E2 transition to the lower-lying yrast level with $J_{f=}J_i$-2 in this case, the γ-ray half-life $T_{1/2}^{\gamma}$ of the E2 transition is (Venkova and Andrejtscheff, 1981).

$$T_{1/2}^{\gamma} = T_{1/2}\,(exp)\,(1 + \alpha_{tot}) \quad (1)$$

where α_{tot} is the total internal conversion coefficient of gamma transition and $T_{1/2}\,(expt)$ is experimental half-life, is related to downward reduced transition probability B(E2) in units of e^2b^2 (Venkova and Andrejtscheff, 1981).

$$T_{1/2}^{\gamma}(second) = \frac{56.57}{B(E2)\downarrow E_{\gamma}^{5}(keV)} \quad (2)$$

where $E\gamma$ is adopted γ-ray energies. The upward transition probability $B(E2)\uparrow$ is related to this value (Venkova and Andrejtscheff, 1981).

$$B(E2,J_i \rightarrow J_f) \downarrow = B(E2,J_f \rightarrow J_i) \uparrow \times g \quad (3)$$

with

$$g = \frac{(2J_f+1)}{(2J_i+1)} \quad (4)$$

Mean while the value of B(E2) in units of e^2b^2, is related to B(E2) in units of Weisskopf single particle transition (W.u) (Schreckenbach et al., 1982).

$$B(E2)w.u = 5.94 \times 10^{-6} \times A^{4/3} \times B(E2)\,e^2b^2 \quad (5)$$

For the low-lying levels of even-even nuclei decay with more than one gamma transition, $T_{1/2}^{\gamma}$ is related to half-life, $T_{1/2}$ by the following equation (Firestone et al., 1999).

$$T_{1/2}^{\gamma}(k) = T_{1/2}\sum_{i=1}^{n}\frac{I_i(1+\alpha_{i\,tot})}{I_k} \quad (6)$$

where the summation is taken over the intensity (I_i) of all gamma transition from the exciting level, I_k is the intensity of k_{th} (E2) transition.

Quadrupole moments

The intrinsic quadrupole moments of nuclei can be derived from the transition rate $B(E2,J \rightarrow J-2)$ values according to Equation (7) (Venkova and Andrejtscheff, 1981).

$$B(E2) = \frac{15}{32\pi}\frac{(J-1)}{(2J-1)}\frac{J}{2(J+1)}e^2\,Q_0^2\,(J \rightarrow J-2) \quad (7)$$

the quadrupole moment $Q(J)$ is related to Q_0 by (El-Khosht, 1993).

$$Q(J) = \frac{3k^2-J(J+1)}{(J+1)(2J+3)}\,Q_0 \quad (8)$$

And in the considered of the ground state J=k,

$$Q(J) = \frac{J(2J-1)}{(J+1)(2J+3)}\,Q_0 \quad (9)$$

The quantity $\hbar\omega$ and moment of inertia $\Im$ have been derived by means of the familiar relation (Venkova and Andrejtscheff, 1981).

$$\hbar^2\omega^2 = (J^2-J+1)\left[\frac{E(J\rightarrow J-2)}{2J-2}\right]^2 \quad (10)$$

and

$$\frac{2\Im}{\hbar^2} = \frac{4J-2}{E(J\rightarrow J-2)} \quad (11)$$

Here, $E(J \rightarrow J-2)$ is the level spacing between states with spin J and J-2 and corresponds to the γ-ray transition energy E_{γ}.

Deformation parameters

If one assumes a uniform charge distribution out to the distance R (θ, φ) and zero charge beyond that, then he finds that in the limit of small deformation, the quadrupole deformation parameters β is related to the formula (Chandan et al., 2004) .

$$\beta = [B(E2)\uparrow]^{\frac{1}{2}}[3ZR_0^2/4\pi]^{-1} \quad (12)$$

where R_0 is the average radius of the nucleus, and (Raman et al., 2001)

$$R_0^2 = 0.0144\,A^{2/3}\,b \quad (13)$$

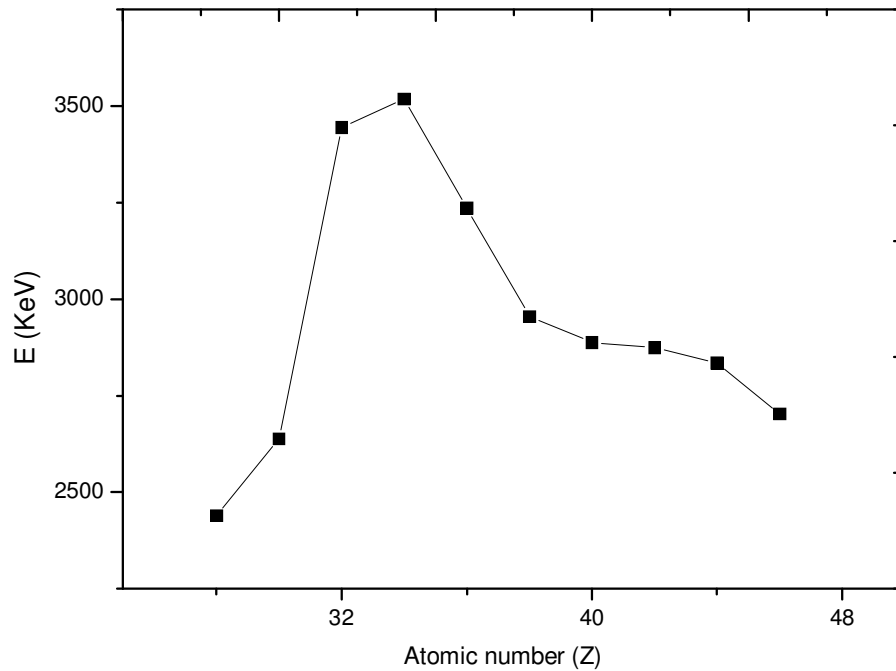In the mean time, the single particle deformation β_{2SP} is given by (Raman et al., 1987).

Figure 1. Energy levels 8[+ as] a function of atomic number (Z) for even-even [76]Ni to [94]Pd nuclei*. **(Mazzocchi et al., 2005; Makishima et al., 1999; Abriola et al., 2009; Singh, 2001; Mukherjee and Sonzogni, 2005;Baglin, 1992; Rsel et al., 1978; Band et al., 1976;Browne, 1997).

$$\beta_{2SP} = 1.59/Z \qquad (14)$$

where, Z is atomic number.

The main deformation parameters (El-Khosht, 1993).

$$\delta = 0.895\beta^2$$

RESULTS AND DISCUSSION

Half-life ($T_{1/2}$)

The results obtained in this study is the most simple and powerful for performing the nuclear model in calculating parameters specified by nuclear structure. In the present work, the value of E_γ were arising from nuclear level $8^+ \rightarrow 6^+$ with corresponding value of B(E2) in units of (W.u), as well as α_{tot} and I_γ values for all gamma transition were accumulated from (Mazzocchi et al., 2005; Makishima et al., 1999; Abriola et al., 2009; Singh, 2001; Mukherjee and Sonzogni, 2005; Baglin, 1992; Rsel et al., 1978; Band et al., 1976; Browne, 1997). The value

of $B(E2)\downarrow$ in units of e^2b^2 for 8^+ state were calculated for 10 even-even nuclei in the mass range A=76→94, using Equation (5). However, the values $T_{1/2}$ of 8^+ states were evaluated using Equations (2 and 6). Figure 1 shows the systematic isomeric levels of experimental low-ling yrast 8^+ state as a function of Z for even-even nuclei [76]Ni to [94]Pd. The energy of 8^+ level increases towards higher proton up to Z= 34, and then decreases up to Z = 46. The maximum isomeric level is 3236 KeV for [82]Se nucleus and minimum value is 2440 KeV for [76]Ni nucleus.

Figure 2 shows reduced transition probability $B(E2)\downarrow$ in e^2b^2 as a function of Z number for N = 48 Isotones from [76]Ni to [94]Pd. The maximum value of B(E2) is 0.0070 e^2b^2 for [90]Mo nucleus, while the minimum value is 0.0008 e^2b^2 for [80]Ge nucleus. The B(E2) values as well as isomeric level do not show the similar tendency as a function of atomic number Z. The $B(E2)\downarrow$ values of the N = 48 Isotones with Z ≤ 38 differ significantly from those with Z ≥ 38. The difference probably originates from the orbital occupied by valence proton; in the former nuclei the valence proton mainly occupy; the f p orbitals while in the
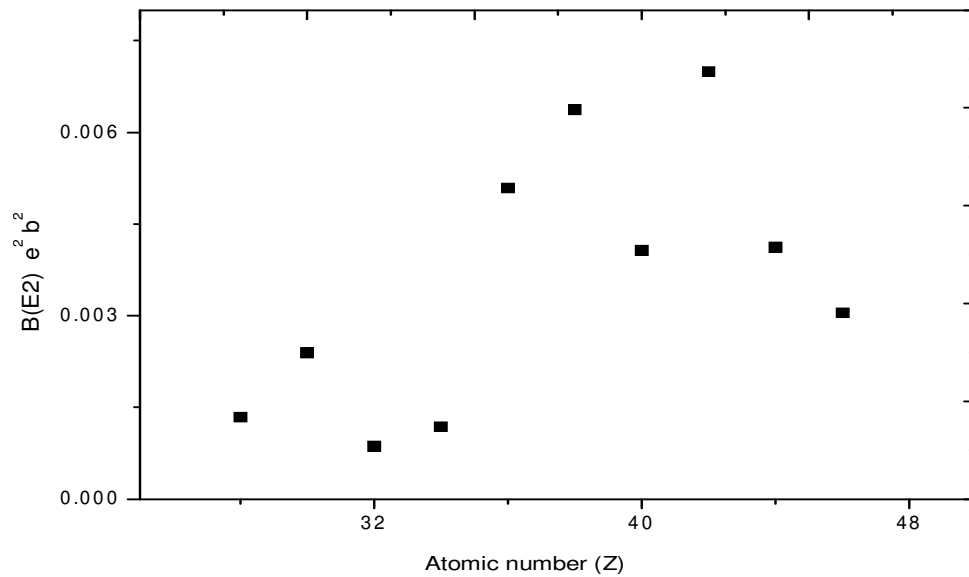
Figure 2. Reduced transition probabilities B(E2)↓ as function of atomic number (Z) for even-even ^{76}Ni to ^{94}Pd nuclei.
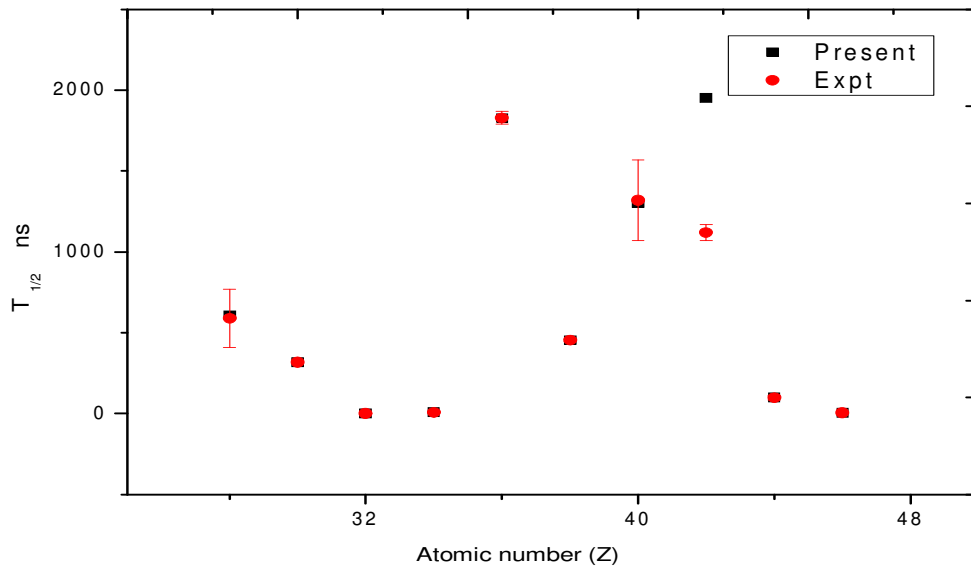

Figure 3. Half-lives of 8^+ levels as a function of atomic number (Z) for even-even ^{76}Ni to ^{94}Pd nuclei*. *(Mazzocchi et al., 2005; Makishima et al., 1999; Abriola et al., 2009; Singh, 2001; Mukherjee and Sonzogni, 2005; Baglin, 1992; Rsel et al., 1978; Band et al., 1976; Browne, 1997).

letter they occupy the $g_{9/2}$ orbital.

Figure 3 shows the calculated and experimental values of half-lives in ns as a function of Z number for N=48 isotones from ^{76}Ni to ^{94}Pd nuclei. It was found that the calculated data overlap to experimental values except Z= 42.
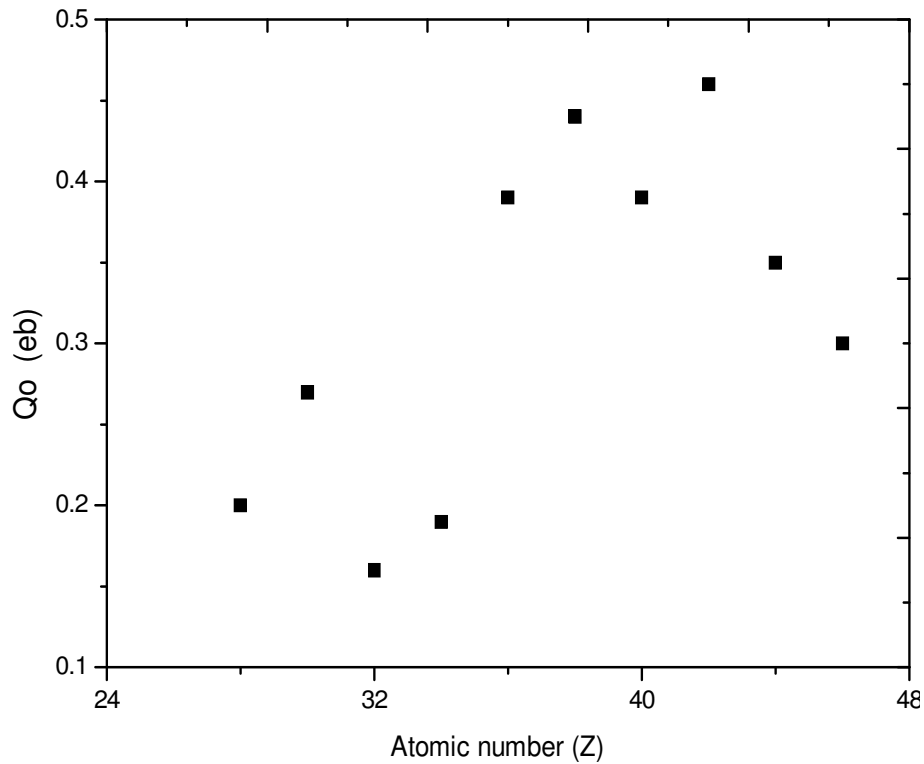
Figure 4. Intrinsic quadrupole moment (Qo)of 8+ levels as function of atomic number (Z) for even-even ^{76}Ni to ^{94}Pd nuclei.

Quadrupole moments

We have calculated the values of Q_0, $Q(J)$, $\hbar^2\omega^2$ and $2\Im/\hbar^2$ for even-even nuclei N = 48. One can conclude that the evaluated intrinsic quadrupole moment are in good agreement with corresponding values of Q_0, which have been experimentally done already by the other authors (Abriola et al., 2009; Mukherjee and Sonzogni, 2005; Browne, 1997). The maximum difference in Q_0 values, however, is found to be 0.12 eb, according to Equation 7. Figure 4 shows that the Q_0 values increase with proton number from Z = 32 to 38, then decrease on semi-magic number Z = 40 and then increases again at Z = 42, after that they are continually decreases until Z=46. The shape of the changing Q_0, B(E2) and β/β_{2SP} as a function of atomic number Z for even-even nuclei ^{76}Ni to ^{94}Pd are similar. Furthermore, the information on quantities $\hbar^2\omega^2$ and $2\Im/\hbar^2$ were calculated, so far in the 8$^+$ levels of doubly even nuclei from ^{76}Ni to ^{94}Pd are represented in Table 1.

Deformation parameter (β)

In Table 2, the values $B(E2)\uparrow$,β and β_{2SP} were calculated from Equations 3, 12 and 14 respectively. The values of ratio β to β_{2SP} and δ were also computed. From Table 2, one can observe that the maximum values of β and β/β_{2SP} are 0.03 and 0.67 for ^{86}Sr and ^{90}Mo nuclei respectively, while the minimum values are 0.01 and 0.25 for ^{80}Ge nucleus. The values of β/β_{2SP} as a function of atomic number (Z) were graphically presented in Figure 5. It is shown that the ratio β/β_{2SP} strong dependence on the atomic number Z. The β/β_{2SP} values increase with increase of proton number from Z=32 to 38, then decrease on semi-magic number Z=40 and then increases again at Z=42. After that they are decreasing until Z=46. The pattern of theβ/β_{2SP}, B (E2) and Q_0, as a function of atomic number Z for even-even nuclei ^{76}Ni to ^{94}Pd is similar. Usually deformation

Table 1. Reduced transition probabilities B(E2) and half-lives $T_{1/2}$ of the 8$^+$ state .

Nuclei	Isomeric levels* (keV)	E_γ (E2) KeV $8^+ \to 6^+$	B.R (%) **	$B(E2)\downarrow$ in units		$T_{1/2}$	
				W.u *	e^2b^2	$T_{1/2(present)}$	$T_{1/2(exp)}$ *
^{76}Ni	2440(1)	144(2)	100	0.7(2)	0.0013	608.90 ns	590(180) ns
^{78}Zn	2637.7(10)	144.7(5)	100	1.21	0.0024	319.56 ns	319(9) ns
^{80}Ge	3445.11(8)	466.76(4)	100	0.422(9)	0.0009	2.95 ns	2.95(6) ns
^{82}Se	3518.5(5)	347(7)	100	0.56(3)	0.0012	8.60 ns	6.6(4) ns
^{84}Kr	3236.07(18)	63.5(1)	100	2.33(6)	0.0051	1.83 µs	1.83(4) µs
^{86}Sr	2955.68(21)	96.68(3)	100	2.83(10)	0.0064	0.46 µs	0.455(7) µs
^{88}Zr	2887.79(6)	76.99(1)	100	1.75(3)	0.0041	1.30 µs	1.32(25) µs
^{90}Mo	2874.73(15)	63.15(1)	100	2.92(13)	0.0070	1.95 µs	1.12(5) µs
^{92}Ru	2834.6(20)	161.9(4)	100	1.672(24)	0.0041	100.21 ns	100 (14) ns
^{94}Pd	2702.13(20)	324(1)	100	≥ 1.2	0.0030	5.08 ns	≤ 5 ns

*(Mazzocchi et al., 2005; Makishima et al., 1999; Abriola et al., 2009; Singh, 2001; Mukherjee and Sonzogni, 2005; Baglin, 1992; Rsel et al., 1978; Band et al., 1976; Browne, 1997). **(Chakraborty et al., 2004; Firestone et al., 1999).

Table 2. The Intrinsic quadrupole moment (Qo), quadrupole moment $Q(J)$, quantity $\hbar^2\omega^2$, moment of inertia $2\Im/\hbar^2$, reduced transition probability $B(E2)\uparrow$ and deformation parameter (β) of the 8$^+$ of even-even nuclei for N=48.

Nuclei	$Qo_{(ex)}$*** (eb)	Qo (eb)	$Q(J)$ (eb)	$\hbar^2\omega^2$ 10^{-3}(MeV^2)	$2\Im/\hbar^2$ (MeV^{-1})	$B(E2)\uparrow$ (e^{2}b^2)	β	β_{2SP}	β/β_{2SP}	$\delta_{10^{-3}}$
^{76}Ni		0.20	0.14	5.25	208.33	0.0010	0.0190	0.0567	0.335	0.324
^{78}Zn		0.27	0.18	5.30	207.32	0.0018	0.0227	0.0530	0.429	0.464
^{80}Ge		0.16	0.11	55.19	64.27	0.0007	0.0125	0.0496	0.253	0.141
^{82}Se		0.19	0.13	30.50	86.45	0.0009	0.0136	0.0467	0.291	0.166
^{84}Kr	0.36(4)	0.39	0.27	1.02	472.44	0.0039	0.0263	0.0441	0.596	0.619
^{86}Sr		0.44	0.30	2.40	304.01	0.0049	0.0274	0.0418	0.656	0.674
^{88}Zr	0.51(3)	0.39	0.24	1.50	389.66	0.0031	0.0205	0.0397	0.515	0.376
^{90}Mo	0.58(3)	0.46	0.32	1.01	475.05	0.0053	0.0252	0.0378	0.668	0.571
^{92}Ru		0.35	0.24	6.56	185.29	0.0031	0.0187	0.0361	0.518	0.314
^{94}Pd		0.30	0.21	26.59	92.59	0.0024	0.0148	0.0345	0.429	0.196

***(Abriola et al., 2009; Mukherjee and Sonzogni, 2005; Browne, 1997).

parameter should be very small near to shell closer, therefore our study for deformation parameters are good agreement with theoretical interpretation.

Conclusion

We have presented the calculated half-lives of the 8$^+$ levels, reduced transition probabilities, quadrupole moments and deformation parameters for even-even ^{76}Ni to ^{94}Pd nuclei. The calculated half-lives and Q_0 as well as experimental data are in good agreement. These results are quite useful for compiling to nuclear data table, which makes it a good reference containing $T_{1/2}$, Q_0, $Q(J)$,

$\hbar^2 \omega^2$, $2\Im/\hbar^2$, β, and β_{2SP}.

REFERENCES

Abriola D, Bostan M, Erturk S, Fadil M, Galan M, Juutinen S, Kibédi T, Kondev F, Luca A, Negret A (2009). Nuclear Data Sheets for A= 84. Nucl. Data Sheets, 110(11): 2815-2944.

Baglin C (1992). Nuclear Data Sheets for A= 92*. Nucl. Data Sheets, 66(2): 347-449.

Band I, Trzhaskovskaya M, Listengarten M (1976). Internal conversion coefficients for atomic numbers Z≤30. Atomic Data Nucl. Data Tab., 18(5): 433-457.

Browne E (1997). Nuclear data sheets for A= 90. Nuclear Data Sheets, 82(3): 379-546.

Chakraborty A, Ghugre S, Goswami R, Mukhopadhyay S, Pattabiraman N, Ray S, Sinha A, Sarkar S, Madhusudhana Rao P, Garg U (2004). Lifetime measurements of microsecond isomers in the N= 48 nuclei 88Zr and 90Mo using recoil-isomer tagging. Phys. Rev. C., 70(1): 14311.

El-Khosht M (1993). Transition rates in level structure of doubly even ytterbium isotopes. Il Nuovo Cimento A, (1971-1996), 106(7): 875-883.

Firestone R, Baglin C, Chu S (1999). Table of Isotopes: 1999 Update with CD-Rom. John Wiley & Sons.

Gorska M, Grawe H, Foltescu D, Fossan D, Grzywacz R, Heese J, Maier K, Rejmund M, Roth H, Schubart R (1995). Proton-neutron interaction at N=Z First observation of the Tz=1 nucleus 94Pd48 in-beam. Zeitschrift für Physik A Hadrons Nuclei, 353(3): 233-234.

Grzywacz R (2005). The structure of nuclei near 78Ni from isomer and decay studies. Eur. Phys. J. A., 25(Supplement 1): 1-1.

Makishima A, Asai M, Ishii T, Hossain I, Ogawa M, Ichikawa S, Ishii M (1999). g 8+isomers in 82Se48 and 80Ge48 populated by deep-inelastic collisions. Phys. Rev. C., 59(5): 2331-2333.

Mazzocchi C, Grzywacz R, Batchelder J, Bingham C, Fong D, Hamilton J, Hwang J, Karny M, Krolas W, Liddick S (2005). Low energy structure of even-even Ni isotopes close to 78Ni. Phys. Lett. B., 622(1-2): 45-54.

Mrginean N, Bucurescu D, Rossi Alvarez C, Ur C, Skouras L, Johnstone L, Bazzacco D, Lunardi S, de Angelis G, Axiotis M (2003). Yrast isomers in 95Ag,95Pd, and 94Pd. Phys. Rev. C., 67(6): 61301.

Mukherjee G, Sonzogni A (2005). Nuclear Data Sheets for A= 88. Nucl. Data Sheets, 105(2): 419-556.

Raman S, Malarkey C, Milner W, Nestor C (1987). Transition probability, B (E2) [short up arrow], from the ground to the first-excited 2+ state of even-even nuclides* 1. Atomic Data Nucl. Data Tab., 36(1): 1-96.

Raman S, Nestor Jr C, Tikkanen P (2001). Transition probability from the ground to the first-excited 2+ state of even-even nuclides. Atomic Data Nucl. Data Tab., 78(1): 1-128.

Rsel F, Fries H, Alder K, Pauli H (1978). Internal conversion coefficients for all atomic shells. Atomic Data Nucl. Data Tab., 21(2-3): 91-289.

Sawicka M, Pfützner M, Grzywacz R, Daugas J, Matea I, Lewitowicz M, Grawe H, Becker F, Belier G, Bingham C (2003). Evidence for an isomer in 76Ni. Eur. Phys. J. A-Hadrons Nuclei, 20(1): 109-110.

Schreckenbach K, Mheemeed A, Barreau G, von Egidy T, Faust H, Boerner H, Brissot M (1982). The importance of intruder states in 114Cd. Phys. Lett. B., 110(5): 364-368.

Singh B (2001). Nuclear Data Sheets for A= 86. Nucl. Data Sheets, 94(1): 1-130.

Sun Y (2008). Projected shell model description for nuclear isomers. Revista Mexicana Defisca, S54(3): 122-128.

Venkova T, Andrejtscheff W (1981). Transition strengths B (E2) in the yrast bands of doubly even nuclei 1. Atomic Data Nucl. Data Tab., 26(2): 93-136.