Comparative Study of Some Nuclear Structure Properties of ^{108,110,112}Pd Isotopes Calculated by Different Theoretical Models

Jasvinder Singh, Dr. Suram Singh

Abstract— The results of nuclear structure properties like reduced transition probabilities B(E2) and deformation parameter (β) of even-even $^{108-112}$Pd isotopes obtained by Cranked Hartree-Bogoliubov (CHB) calculations and Interaction Boson Model (IBM-I) are compared. The comparison is also made with the experimental values.

Index Terms— Nuclear Structure Properties, B(E2), Deformation Parameter, Theoretical Models.

---

1 Introduction

The nucleus is the very dense region consisting of protons and neutrons at the centre of an atom. It was discovered in 1911 by Ernest Rutherford [1]. Almost all of the mass of an atom is located in the nucleus, with a very small contribution from the orbiting electrons. The branch of physics concerned with studying and understanding the atomic nucleus, including its composition and the forces which bind it together, is called nuclear physics. In the nuclear theoretical physics, we study a variety of nuclear structure phenomenon. One of the main research lines are the study of nuclear structure and reaction mechanism of the nuclei. Besides this, the concept of deformation in nuclei is widely studied now-a-days. The concept of nuclear deformation is very useful and efficient tool to analyse various properties of non magic nuclei. In recent years, one of the main tasks of the nuclear research is the study of exotic nuclei in the region of deformation. The exotic nuclei are those nuclei which are far away from the β-stability line. Nuclear research in sixties and seventies was concentrated mainly upon the study of properties of nuclei along β-stability line. However, with the development of sophisticated high precision measuring devices, it became possible to investigate the properties of nuclei which are far away from the β-stability line. The research in nuclear structure Physics reached a new height with the advancement in the development of accelerators and efficient γ-ray detectors. This made it possible to carry out nuclear reactions where in new nuclei could be produced in highly excited states, which, in turn, decayed to their ground state by emitting a cascade of γ-rays.

- *Jasvinder Singh is currently working as Assistant Professor in Physics in Govt. Degree College, Kathua, (J&K), India-184101.*
  E-mail: jasvinderkah076@gmail.com
- *Dr. Suram Singh is currently working as Assistant Professor in Physics in Govt. Degree College, Kathua, (J&K), India-184101.*
  E-mail: suramsingh@gmail.com

The nuclei in the nuclear deformation region have been studied in the past by a variety of both, experimental and theoretical methods, thereby, furnishing a plenty of data for comparison with new and improved theoretical description. From the review of the literature, available so far, it is found that the nuclei in the mass region A~110 have variety of structure phenomenon, such as:

- Shape coexistence
- Rapid change of shape from prolate to oblate.
- Triaxial shape, etc. and provide a rich testing ground for studying them in a microscopic framework.

2 Review of Literature

The study of ground-state properties of even mass palladium isotopes has been the subject of a large number of experimental studies [2–19]. In recent years, the experimental techniques such as Coulomb excitation and γ-ray spectroscopy have extended the new level schemes of some of these nuclei up to 16^+. In contrast to the large scale effort that has been made on the experimental side, only a few theoretical models [20–23] have been proposed to explain the character of yrast spectra in these nuclei. The earliest phenomenological attempt at understanding the observed levels in the Pd region have had limited success [21]. Apart from the earlier studies in the framework of the variable moment of inertia (VMI) model, an attempt was also made by Smith and Valkov[22] to explain the observed features of the yrast bands in Pd isotopes by invoking instability towards asymmetric deformation at sufficiently high ($J^\pi > 8^+$) angular momenta. The Interacting Boson Model-1 (IBM-1) of Arima and Lanchello [23, 24] has been widely accepted in describing the collective nuclear structure by the prediction of the low-lying states and the description of electromagnetic transition rates in the medium mass nuclei. Sometime back Stachel et al. [25] attempted a study of the experimental excitation energies and E2 transition probabilities of the neutron-rich Pd isotopes in the framework of interacting boson model (IBM-I). It has been established by them that palladium isotopes follow the SU(5)→O(6) transition. The mechanism of this shape transition is not very clear from their calculation. Sometime back Aysto.et al. [26] suggested the importance of triaxiality in neutron rich nuclei in the mass region A~108. Shannon et al.[27] have also recently reported the occurrence of axially asymmetric shapes in neutron rich nuclei in the mass region A~100. Ostensibly, one feels motivated to examine the degree to which nuclear low-lying states in $^{108–112}$Pd could adopt axially asymmetric shapes. Such a possibility prompts us to ask a number of questions such as, how good will the non axial calculations for the mass chain of $^{108–112}$Pd be? Secondly, how reliable are the calculations, performed with different theoretical models.This has been the inspiring factor for us to execute the present work. In that direction, we have tried to compare results of some of the nuclear structure properties of even-even $^{108\text{-}112}$Pd isotopes lying in the mass region A~110 calculated by Cranked Hartree-Bogoliubov (CHB) [28] with Interacting Boson Model (IBM-I) [29].

3 Theoretical Models

3.1 Cranked Hartree-Bogoliubov (CHB): In A. Pandoh et. al [28], they have carried out a study of yrast states, quadrupole moments, quadrupole deformation parameter (β) , B(E2) transition probabilities, and occupation probabilities of $^{108\text{-}114}$Pd isotopes in cranking framework. They have employed the cranked Hartree-Bogoliubov (CHB) frame work in conjunction with the HB ansatz. They had done the calculations by including a higher order octupole-octupole energy term (PPQO) operating in a reasonably large valence space. The nucleus ^{76}Sr has been considered as an inert core.

3.2 Interacting Boson Model (IBM-I): In I. Hossain et. al. [29], they have used Interacting Boson Model (IBM-1) for calculating the systematic reduced transition probabilities B(E2), intrinsic quadrupole moments and deformation parameter of $^{108\text{-}112}$Pd isotopes.

4 Comparison and Discussions:

4.1 Comparison of B(E2) transition probabilities:
In Table 1, the comparison of reduced transition probabilities B(E2) of transition level $2^+ \rightarrow 0^+$ of even-even $^{108\text{-}112}$Pd calculated by CHB [28] and IBM-1[29] have been presented. The comparison is also made with the experimental values [30,31,32]. In case of ^{108}Pd, the B(E2) calculated by IBM-1 i.e. 0.755 is more close to experimental value i.e. 0.761 than the 0.77 as calculated by CHB. For ^{110}Pd, the experimental value is 0.87 whereas the calculated values from IBM-1 and CHB are 0.855 and 0.73 respectively. Again it is clear that the B(E2) calculated by IBM-1 is more close to experimental value. In case of ^{112}Pd, again the calculated value by IBM-1 i.e. 0.655 is more close to experimental i.e. 0.66 as compared to value 0.81 calculated by CHB. From the above discussion it is clear that IBM-1 produces more good results as compared to the CHB in case of $^{108\text{-}112}$Pd. The same results are also depicted in Fig.1.

Table 1 Comparison of experimental B(E2;$0^+ \rightarrow 2^+$) values with calculated values from Interacting Boson Model (IBM-1) and Cranked Hartree-Bogoliubov (CHB). The B(E2) values are in units of e^2b^2. Experimental values are taken from [30,31,32].

Nuclei	Transition	B(E2)↑ Expt.* (e^2b^2)	B(E2)↑ IBM-I (e^2b^2)	B(E2)↑ CHB (e^2b^2)
^{108}Pd	$0^+ \rightarrow 2^+$	0.761(23)	0.755	0.77
^{110}Pd	$0^+ \rightarrow 2^+$	0.870(40)	0.855	0.73
^{112}Pd	$0^+ \rightarrow 2^+$	0.66(11)	0.655	0.81

Table 2 Comparison of experimental Deformation Parameter (β) values with calculated values from Interacting Boson Model (IBM-1) and Cranked Hartree-Bogoliubov (CHB). Experimental values are taken from [30,31,32].

Nuclei	Transition	β (Expt.)*	B (IBM-I)	β (CHB)
^{108}Pd	$0^+ \rightarrow 2^+$	0.761(23)	0.755	0.77
^{110}Pd	$0^+ \rightarrow 2^+$	0.870(40)	0.855	0.73
^{112}Pd	$0^+ \rightarrow 2^+$	0.66(11)	0.655	0.81

4.2 Comparison of Deformation Parameter (β): In Table 2, the comparison of deformation parameter (β) of transition level $2^+ \rightarrow 0^+$ of even-even $^{108\text{-}112}$Pd calculated by CHB [28] and IBM-1[29] have been presented. The comparison is also made with the experimental values [30,31,32]. In case of ^{108}Pd, the β calculated by IBM-1 i.e. 0.242 is more close to experimental value i.e. 0.243 than the 0.254 as calculated by CHB. For ^{110}Pd, the experimental value is 0.255 whereas the calculated values from IBM-1 and CHB are 0.257 and 0.239 respectively. Again it is clear that the β calculated by IBM-1 is more close to experimental value. In case of ^{112}Pd, again the calculated value by IBM-1 i.e. 0.221 is more close to experimental i.e. 0.220 as compared to value 0.210 calculated by CHB. From the above discussion it is clear that IBM-1 produces more good results as compared to the CHB in case of $^{108\text{-}112}$Pd. The same results are also depicted in Fig.2.

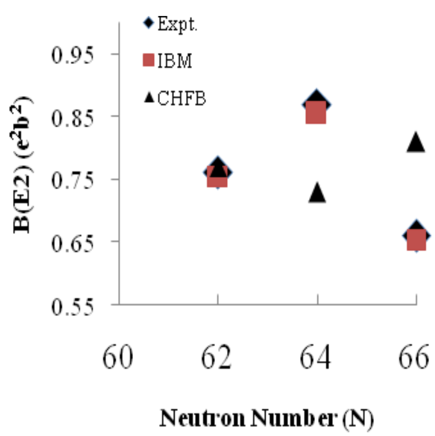

Fig. 1. The B(E2) vs. the neutron number of ^{108,110,112}Pd isotopes

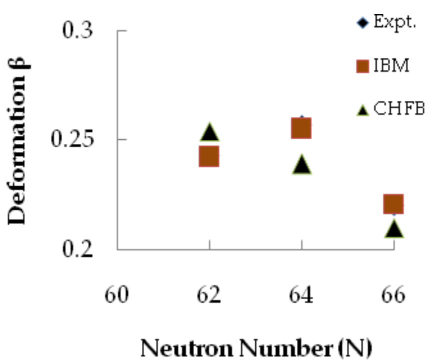

Fig. 2. The deformation β vs. the neutron number of ^{108,110,112}Pd isotopes

5 Conclusions:

We compare the results of two theoretical models viz. Cranked Hartree-Bogoliubov (CHB) [28] calculations with Interacting Boson Model (IBM-I) [29] calculations on reduced transition probabilities B(E2) and deformation parameter (β) of even-even $^{108\text{-}112}$Pd isotopes. Also the results of two models are compared with the experimental values. From the comparison, it is clear that IBM-1 produces more good results as compared to the CHB for B(E2) and β in case of even-even $^{108\text{-}112}$Pd. The comparison also predicts the reliability of discussed theoretical models in the mass region A~110.

6. References

[1] E. Rutherford, "The Scattering of α and β Particles by Matter and the Structure of the Atom", Phil. Mag. **21**, 669, 1911.

[2] T. Tamura and T. Udagawa, "Static Quadrupole Moment of the First 2^+ State of Vibrational Nuclei", Phys. Rev. 150, 783, 1966.

[3] R. L. Robinson et. al. "Coulomb excitation of $^{106,\,108,\,110}$Pd", Nucl. Phys. A124, 553, 1969.

[4] E. Cheifetz et. al. "Experimental Information Concerning Deformation of Neutron Rich Nuclei in the A∼100 Region", Phys. Rev. Lett. 25, 38, 1970.

[5] A. Christy et. al. "Measurement of the static quadrupole moments of the first 2^+ states in $^{104,\,106}$Pd and ^{130}Te", Nucl. Phys. A142, 591, 1970.

[6] T. A. Doron and M. Blann, "The decay of ^{104}, ^{104m}Ag, ^{104}, ^{104m}Rh and levels of ^{104}Pd" Nucl. Phys. A171, 273, 1971.

[7] K. Okano, Y. kawase and H. Uehara, "Levels and transitions in ^{104}Pd from the decay of ^{104m}Rh and ^{104g}Rh", Nucl. Phys. A182, 131, 1972.

[8] C. M. Lederer and V. S. Shirley, "Table of Isotopes", 7th ed., Wiley, New York, 1978.

[9] H. I. Hayakawa, I. Hyman, and J. K. P. Lee, "Decay of ^{100}Ag" Phys. Rev. C22, 247, 1980.

[10] L. K. Pekker, "Nuclear Data Sheets for A = 112", Nucl. Data Sheets 29, 587, 1980.

[11] W. F. Piel, G. Scharff-Goldhaber, A. H. Lumpkin, Y. K. Lee, and D. C. Stromswold, "Level schemes of ^{102}Pd and ^{100}Pd", Phys. Rev. C 23, 708, 1981.

[12] P. De Gelder, E. Jacobs, and D. De Frenne, "Nuclear data sheets for A = 110", Nucl. Data Sheets 38, 545, 1983.

[13] M. Sakai, "Quasi-bands in even-even nuclei", At. Data Nucl. Data Tables 31, 399, 1984.

[14] D. Cline, "Nuclear Shape studied by Coulomb Excitation", Annu. Rev. Nucl. Part. Sci. 36, 683, 1986.

[15] D. De Frenne, E. Jacobs, M. Verboven, and G. De Smet, " Nuclear data sheets for A = 106" Nucl. Data Sheets 53, 73, 1988.

[16] J. Aysto et. al. "Levels in ^{110}Pd, ^{112}Pd, ^{114}Pd and ^{116}Pd from the beta decays of the on-line mass separated Rh isotopes" Nucl. Phys. A 480, 104, 1988.

[17] R. Aryaeinejad et. al. "Band crossing observed in neutron-rich Pd isotopes via spontaneous fission of ^{252}Cf", Phys. Rev. C48, 566, 1993.

[18] J. Balachot, "Nuclear data sheets update for A = 108", Nucl. Data Sheets 62, 803, 1991.

[19] J. Balachot and G. Marquier, "Nuclear Data Sheets Update for A = 114", Nucl. Data Sheets 75, 739, 1995.

[20] G. Scharff-Goldhaber, M. McGowen, A. H. Lupkin and W. F. Piel,"Forking" of ground state bands in ^{102}Pd and ^{100}Pd", Phys. Lett. 44B, 416, 1973.

[21] M. A. J. Mariscotti, G. Scharff-Goldhaber and B. Buck, "Phenomenological Analysis of Ground-State Bands in Even-Even Nuclei",Phys. Rev. 178, 1864, 1969.

[22] B. C. Smith and A. B. Valkov, "An explanation for forking and backbending in rotational spectra", Phys. Lett. 47B, 193, 1973.

[23] F. Iachello and A. Arima, "Boson symmetries in vibrational nuclei", Phys. Lett. B 53, 304, 1974.

[24] A. Arima and F. Iachello, "Collective Nuclear States as Representations of a SU(6) Group", Phys. Rev. Lett. 35, 1069, 1975.

[25] J. Stachel, P. Van Isacker and K. Heyde, "Interpretation of the A≈100 transitional region in the framework of the interacting boson model", Phys. Rev. C 25, 650, 1982.

[26] J. Aysto et. al. "Collective structure of the neutron-rich nuclei, ^{110}Ru and ^{112}Ru" Nucl. Phys. A515, 365, 1990.

[27] J. A. Shannon et. al. "The role of triaxiality in the ground states of even-even neutron-rich Ru isotopes" Phys. Lett. B 336, 136, 1994.

[28] A. Pandod, R. Devi and S. K. Khosa "Role of octupole-octupole interaction in neutron-rich $^{108\text{-}114}$Pd isotopes" Phys. Rev. C 59, 129, 1999.

[29] Hossain, H. Y. Abdullah, I. M. Ahmad and M. A. Saeed "B(E2) value of even-even $^{108\text{-}112}$Pd isotopes by interacting boson model-I" Chinese Physics C 38, No. 2, 024103, 2014.

[30] Blachot "Nuclear Data Sheets for A = 108" Nucl. Data Sheets, 81, 599, 1997.

[31] G. Gurdal, F. G. Kondev "Nuclear Data Sheets for A = 110" Nucl. Data Sheets, 113, 1315, 2012.

[32] D. De Frenne and E. Jacobs "Nuclear Data Sheets for A = 112" Nucl. Data Sheets, 79, 639,1996.