SAKARYA UNIVERSITY
JOURNAL OF SCIENCE

e-ISSN: 2147-835X
http://www.saujs.sakarya.edu.tr

Received
26-09-2018
Accepted
14-11-2018

Doi
10.16984/saufenbilder.463978

Pseudo-mirror nuclei in the mass regions A~ 170 and A~ 200

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Abstract

The concept of pseudo-mirror nuclei is based on the $N_\pi N_\nu$ scheme introduced as an extension of the $N_p N_n$ scheme. The $N_\pi N_\nu$ scheme tells us that if two nuclei from different mass region have equal number of integrated n-p interaction than the experimental observables E(2+), $E(4^+)/E(2^+)$ and $B(E2; 2^+ \rightarrow 0^+)$ are expected to be almost equal, therefore equal number of n-p interaction build similar level schemes up to certain spin quantum numbers. Pseudo-mirror nuclei have been introduced for the first time in the mass regions A ~ 100 and A ~ 130 for Mo, Zr, Nd and Ce nuclei. Later, a systematic work carried out over a broad region of Segre chart showed that not only the excitation energies but also related B(E2) values of excited states in pseudo-mirror nuclei (PMN) are in good agreement. In the present work, we present new pseudo-mirror nuclei in the mass region A ~ 170 and A ~ 200 for the first time.

Keywords: Pseudo-mirror nuclei, n-p interaction, $N_\pi N_\nu$ Scheme

1. INTRODUCTION

Atomic nucleus is a many-body problem in applied quantum mechanics since its discovery in 1911 by Ernest Rutherford [1] while firing alpha particles on gold sheets in the University of Manchester. The discovery itself is an emergent phenomenon. It is quite interesting than nobody has assumed the existence until its discovery [2]. Soon later, the attention from many scientists drawn on nuclei it has been understood that its structure is quite complex. However, searching symmetries make this complexity rather simple over time. Heisenberg introduced the isospin concept which indicates neutron and protons are only different states of a nucleon [3]. Since then mirror nuclei have been a unique laboratory in order to investigate the behavior of different state of nucleon named proton and neutron under the strong nuclear interaction [4,5]. Later, valence mirror and pseudo-mirror nuclei (PMN) have been introduced to understand the underlying structure of isospin symmetry [6-10]. Pseudo-mirror nuclei have been introduced by Moscrop et al [10] over Mo, Zr, Ce and Nd based on the $N_\pi N_\nu$ product, where $N_\pi = p_{p(h)}/2$ i.e. half the number of valence protons (or holes) and $N_\nu = n_{p(h)}/2$ is half the number of valence neutrons (or holes) from the nearest closed shell by considering the subshell closure. The $N_\pi N_\nu$ scheme is based on the $N_p N_n$ scheme introduced by Casten [11], where the latter is a measure of n-p interaction which build the collectivity and deformation in nuclei beyond a major shell. Recent studies on the B(E2) values of excited states in PMN over a broad region of Segre chart revealed that the nuclei having equal $N_\pi N_\nu$ quantity show similar nuclear structural behavior [12,13]. Figure 1 shows ^{108}Ru-^{124}Ba pseudo-mirror nuclei both having $N_\pi N_\nu$ = 21. It is quite surprising that these two nuclei from different mass regions exhibit similar

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level schemes based on their valence proton – neutron interactions. ^{100}Zr-^{164}Hf, ^{136}Sm-^{160}Yb, ^{102}Zr-^{130}Nd, ^{136}Sm-^{160}Yb and ^{168}Hf-^{160}Er nuclei are some of the examples for PMN introduced by Moscrop et.al [10] and Sayğı [12,13].

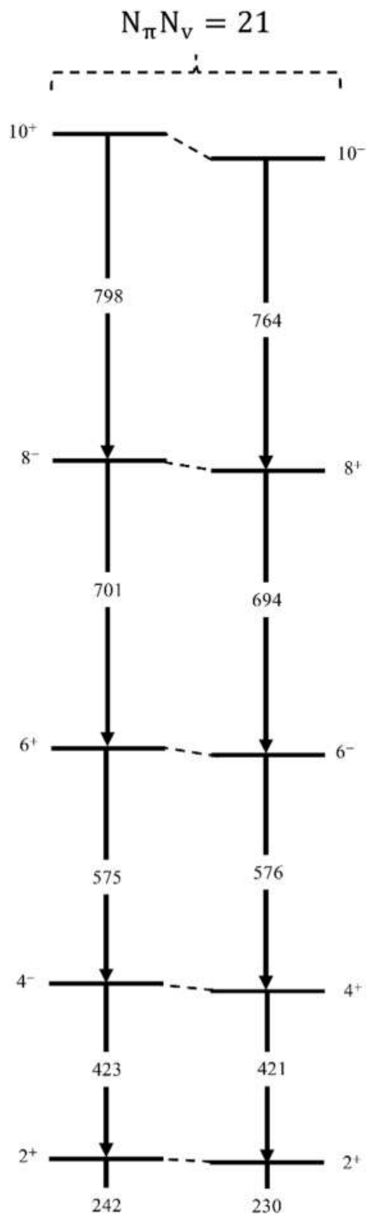

Figure 1: Excitation energies in ^{108}Ru-^{124}Ba level schemes with $N_\pi N_\nu$ = 21. Level schemes adopted from [14,15].

In the present work, we are going to introduce new PMN from the mass region A ~ 170 and A ~ 200. The mass region A ~ 200 have not been investigated yet from the point view of PMN so far. Figure 2 shows the level schemes of ^{164}Os (6p$_h$-6n$_p$) - ^{208}Ra (6p$_p$-6n$_h$), ^{166}Os (6p$_h$-8n$_p$)-^{206}Ra (6p$_p$-8n$_h$) and ^{174}Pt (4p$_h$-14n$_p$) - ^{198}Rn (4p$_p$-14n$_h$) nuclei, where the p$_{p(h)}$ and n$_{p(h)}$ are the quantities which represent the number of valence proton particle (hole) and neutron particle (hole) from the nearest closed proton and neutron shells. The key point in the PMN is the exchange of particle and hole numbers from one of the pairs to the other.

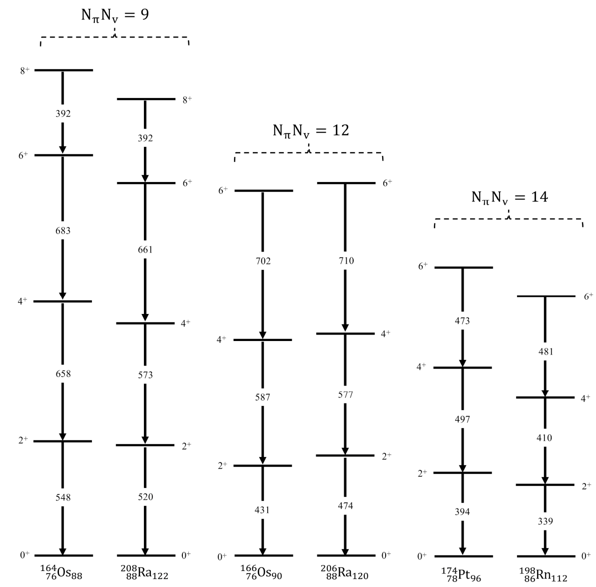

Figure 2: Excitation energies in ^{164}Os [16]-^{208}Ra [17] with $N_\pi N_\nu$ = 9, ^{166}Os [16]-^{206}Ra [18] with $N_\pi N_\nu$ = 12 and ^{174}Pt [19]-^{198}Rn [20] with $N_\pi N_\nu$ = 14.

The nuclei presented in the present manuscript follow general trend in the description of pseudo-mirror nuclei. The energies of excited 2^+ state in ^{164}Os-^{208}Ra, ^{166}Os-^{206}Ra and ^{174}Pt-^{198}Rn are almost degenerate. The second quantity which is employed quite often to determine the pseudo-mirror nuclei is the ratio of E(4^+)/E(2^+). The E(4^+)/E(2^+) is 2.20 for the ^{164}Os and 2.10 for ^{208}Ra with $N_\pi N_\nu$ = 9. The E(4^+)/E(2^+) is 2.36 for the ^{166}Os and 2.21 for ^{206}Ra with $N_\pi N_\nu$ = 12. The E(4^+)/E(2^+) is 2.26 for the ^{174}Pt and 2.20 for ^{198}Rn with $N_\pi N_\nu$ = 14. The difference of 0.1 between the E(4^+)/E(2^+) values in the PMN pairs are in the range of the systematics result proceeded by Sayğı [12]. The E(4^+)/E(2^+) quantity is a good value which indicates the structural features of the nuclei of interest. Therefore, these nuclei are meeting the essential criteria to be accepted pseudo-mirror nuclei in the framework of the $N_\pi N_\nu$ scheme introduced by Moscrop et.al [10]. The last and the most important criteria to define a couple of nuclei having equal $N_\pi N_\nu$ quantity is the reduced transition probabilities of the related excited states in the pseudo-mirror nuclei. However, the required data are not available while the present manuscript is being written. Therefore, we are strongly suggesting the measurement of reduced transition probabilities of excited states in these nuclei. None of the theories provided in Raman [21] systematic work predicts a relation between calculated B(E2) values for the nuclei presented in here. Nonetheless, the $|\beta_2|$ deformations calculated by Möller [22] for ^{164}Os-^{208}Ra with $N_\pi N_\nu$ = 9 in agreement where the values are 0.129 and 0.125, respectively. The theoretical$|\beta_2|$values for ^{166}Os-^{206}Ra and ^{174}Pt-^{198}Rn differ. The reason for this is possible the nuclei of interest in this manuscript have not been considered within the pseudo-mirror nuclei concept. Quadrupole-quadrupole interaction is assumed to establish nuclear structure beyond the closed shells, however, it seems integrated neutron-proton interaction dominates the quadrupole-quadrupole interaction when the number of valence nucleons either particles or holes [23-27]. Therefore, to explain the pseudo-mirror nuclei phenomena one should take account the neutron-proton interaction.

In summary, we have introduced the new pseudo-mirror nuclei ^{164}Os-^{208}Ra with $N_\pi N_\nu$ = 9, ^{166}Os-^{206}Ra with $N_\pi N_\nu$ = 12 and ^{174}Pt-^{198}Rn with $N_\pi N_\nu$ = 14 in the mass regions A ~ 170 and A ~ 200 for the first time. The available data do not let us to examine the reduced transition probabilities of the nuclei of interest in the present manuscript. However, the E(4^+)/E(2^+) ratio still let us to describe the nuclei in the framework geometric collective model limits. Theoretical values have been investigated provided by Raman and Möller. We suggest that a model should consider the integrated proton-neutron interaction to interpret the structure of pseudo-mirror nuclei.

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