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Symmetrical level schemes of the even–even $Sm_{A\approx 130}$ and $Yb_{A\approx 160}$ nuclei up to 10^+ in the yrast bands

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Received 10 September 2018; received in revised form 26 September 2018; accepted 27 September 2018

Abstract

For the first time, we show here that three isotopes of the Sm isotopic chain almost overlay with three isotopes of the Yb isotopic chain in terms of experimental observables within the $N_\pi N_\nu$ scheme. A recent systematic work by Sayğı on reduced transitional probabilities in pseudo-mirror nuclei revealed that nuclei having particle–hole symmetry tend to manifest alike experimental structures. The $N_\pi N_\nu$ quantity is an indicator of the symmetry and depends on valence nucleon (or holes) number from the nearest closed shell by considering the subshell closures, which simplifies the systematics of excitation energies and related B(E2; $L^+ \rightarrow (L-2)^+$) values of excited states in nuclei placed in the different mass regions of nuclear chart. In the light of available data, the experimental observables in the group of ^{136}Sm–^{160}Yb, ^{134}Sm–^{162}Yb and ^{132}Sm–^{164}Yb nuclei have been analyzed in a vertical and horizontal perspectives and the ratio of reduced transition probabilities of the first excited states compared with existing theoretical predictions. The data brought to light that the structure of each group reflects identical yrast bands up to 10^+.

Keywords: Pseudo-mirror nuclei; Reduced transition probabilities; Level schemes

Complexity of excitation modes are built with increasing valence nucleons beyond a major shell. Valence proton–neutron or related hole (n–p) interaction, which is proportional to N_pN_n plays a critical role in enhancing the collectivity and deformation in nuclei. Further details can be found in traditional papers [1–4]. Casten [5,6] later introduced a phenomenological scheme which is manifesting integrated n–p interaction and called the scheme as N_pN_n scheme. The

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https://doi.org/10.1016/j.nuclphysa.2018.09.080
0375-9474/

Please cite this article in press as: B. Sayğı, Symmetrical level schemes of the even–even $Sm_{A\approx 130}$ and $Yb_{A\approx 160}$ nuclei up to 10^+ in the yrast bands, Nucl. Phys. A (2018), https://doi.org/10.1016/j.nuclphysa.2018.09.080

scheme is letting both interpretation of existence data and prediction while studying unknown regions. In the N_pN_n scheme, most of the nuclear observables follow similar trends such as E_{4^+}/E_{2^+}, $E(2^+)$ and $B(E2;2^+ \to 0^+)$ as a function of $N_\pi N_\nu$ in different mass regions. Later, Bhattacharya et al. [7,8] showed that the tunnelling probability of the α-particle decay vary with the number of effective valence nucleons and investigated the fraction of contribution to binding energy difference of experiment and theory. Pseudo-mirror nuclei (PMN) has been introduced to the literature by Moscrop et al. [9] and later Sayğı [10] carried on a systematic work on the excited states and their related reduced transition probabilities of the PMN ranging from Zr to W nuclei. The PMN concept is based on the $N_\pi N_\nu$ quantity inherited from Ref. [5], where N_π is half of the valence protons (or holes) and N_ν is half of valence neutrons (or holes) from the nearest closed shell by considering the subshell closures. In the scheme of PMN, the nuclei with equal number of $N_\pi N_\nu$ manifest similar structure in consequence of particle–hole symmetry; almost equal E_{4^+}/E_{2^+}, $E(2^+)$ and a smooth trend in $B(E2; L^+ \to (L-2)^+)$ as a function of $N_\pi N_\nu$ in different mass regions [5,9,10] up to spin-quantum numbers where the depopulating energies of related excited states do not diverge more than 40 keV. The behaviour of B(E2) values from Ref. [10] are visualized in Fig. 1 and can be summarized as;

- $B(E2; L^+ \to (L-2)^+)_{A\approx130}$ is approximately two times larger than $B(E2; L^+ \to (L-2)^+)_{A\approx100}$,
- $B(E2; L^+ \to (L-2)^+)_{A\approx160}$ is approximately two times larger than $B(E2; L^+ \to (L-2)^+)_{A\approx100}$,
- $B(E2; L^+ \to (L-2)^+)_{A\approx160}$ is approximately equal to $B(E2; L^+ \to (L-2)^+)_{A\approx170}$,

therefore,

- $B(E2; L^+ \to (L-2)^+)_{A\approx160}$ is expected to be approximately equal to $B(E2; L^+ \to (L-2)^+)_{A\approx130}$,

Fig. 1 represents pseudo-mirror ^{102}Mo ($8p_h$–$10n_p$)–^{134}Nd ($10p_p$–$8n_h$), ^{100}Zr ($10p_h$–$10n_p$)–^{164}Hf ($10p_h$–$10n_p$) and ^{168}Hf ($10p_h$–$14p_p$)–^{160}Er ($14p_h$–$10n_p$) nuclei from different mass regions A ≈ 100, A ≈ 130 and ≈ 160/170, where $p_{p(h)}$ for proton particle (hole) and $n_{p(h)}$ for neutron particle (hole). It is quite surprising that equal number of integrated p–n interaction are building a symmetrical level scheme and related B(E2) values in the different mass regions.

Energy levels and related B(E2) values of the ^{136}Sm–^{160}Yb, ^{134}Sm–^{162}Yb and ^{132}Sm–^{160}Yb have been extracted from literature and combined in Fig. 2. The ratios of E_{4^+}/E_{2^+} in ^{136}Sm–^{160}Yb nuclei are 2.69 and 2.62, their related $B(E2)_{4^+/2^+}$ ratio equals to 1.35(19) and 1.39(13) respectively. Both nuclei lie in the vicinity of O(6) symmetry, where the E_{4^+}/E_{2^+} and the $B(E2)_{4^+/2^+}$ ratios are expected to be 2.50 and 1.32 [20]. The β_2 quadrupole deformations from Möller work [21] are 0.237 for ^{136}Sm and 0.208 for ^{160}Yb, both prolate geometry. Table 1 shows B(E2) values in Weisskopf unit for PMN from ^{136}Sm to ^{160}Yb, where the deformation of ^{136}Sm is larger than in ^{160}Yb, which is in agreement with the prediction of theory. For the PMN ^{134}Sm–^{162}Yb, the E_{4^+}/E_{2^+} ratios are 2.93 and 2.93, their related $B(E2)_{4^+/2^+}$ equal to 1.06(10) and 1.52(7) respectively. The excitation energies of both nuclei lie in the vicinity of X(5) symmetry [22], where the E_{4^+}/E_{2^+} is expected to be 2.91. The $B(E2)_{4^+/2^+}$ ratio is accepted 1.58 in X(5) symmetry [22]. The ^{134}Sm nuclide is another example where excitation energies and related B(E2) values disagree. Of course the interpretation is based on existence data, a new measurement using state of art techniques may reveal more precise measurements

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