

Pseudo-mirror nuclei ^{76}Se and ^{80}Kr : A Shell-model perspective

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Introduction

In nuclear physics, the investigation of similarities in two different quantum systems likely began with the mirror nuclei, which have identical energy spectra and isobaric mass multiplets [1]. Similar to the mirror nuclei, the study of pseudo-mirror nuclei provides valuable insights into nuclear structure by highlighting symmetries between nuclei with different proton and neutron configurations [2]. In the framework of the nuclear shell model, pseudo-mirror nuclei are characterized by a unique correlation: one nucleus in the pair has the same number of proton particles (and neutron holes), $N_p(N_n)$ as the neutron holes (and proton particles), $N_n(N_p)$ in the other, within a specific model space. In the $A \approx 80$ mass region, the nuclei ^{76}Se and ^{80}Kr have been identified as pseudo-mirror pairs with $N_pN_n = 48$, displaying notable similarities in their low-energy spectra and kinematic moment of inertia (I/\hbar^2). Apart from this, studying the systematics of $B(E2)$ transitions in the pseudo-mirror nuclei provides crucial information about the quadrupole collectivity and the degree of deformation in these nuclei [3]. In this study, we use the shell-model framework to explore these similarities, offering deeper insights into the underlying proton-neutron interactions in defining the nuclear structure of these two pseudo-mirror nuclei.

Formalism

The jun45 shell-model interaction [4] is utilized in the study of pseudo-mirror nuclei ^{76}Se and ^{80}Kr . We can express the shell-model

Hamiltonian as follows:

$$H = \sum_{\alpha} \varepsilon_{\alpha} \hat{N}_{\alpha} + \frac{1}{4} \sum_{\alpha\beta\delta\gamma JT} \langle j_{\alpha} j_{\beta} | V | j_{\gamma} j_{\delta} \rangle_{JT} \times O_{JT;j_{\alpha} j_{\beta}}^{\dagger} O_{JT;j_{\delta} j_{\gamma}}, \quad (1)$$

where, $\alpha = \{nljt\}$ denotes the single-particle orbitals and ε_{α} stand for the corresponding single-particle energies. $\hat{N}_{\alpha} = \sum_{j_z, t_z} a_{\alpha, j_z, t_z}^{\dagger} a_{\alpha, j_z, t_z}$ is the particle number operator. The two-body matrix elements $\langle j_{\alpha} j_{\beta} | V | j_{\gamma} j_{\delta} \rangle_{JT}$ are coupled to the spin J and isospin T . O_{JT}^{\dagger} , and O_{JT} represent the fermion pair creation and annihilation operators, respectively.

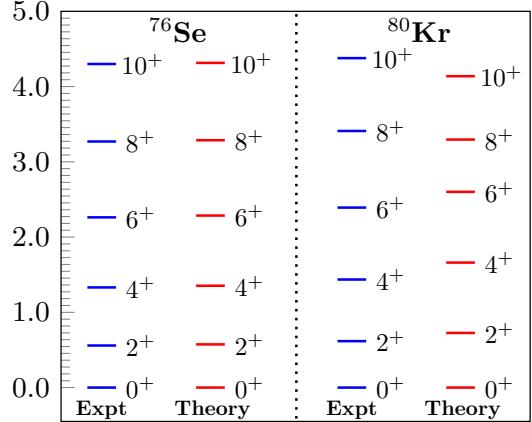


FIG. 1: Comparison of the shell-model predicted states of g.s. bands in the pseudo-mirror nuclei ^{76}Se and ^{80}Kr with the experimental data [5].

The mean-field part of the shell-model Hamiltonian corresponding to the jun45 interaction consists of $0f_{5/2}1p_0g_{9/2}$ proton and neutron orbitals. The KSHELL code [6] is employed for the diagonalization of shell-model Hamiltonian matrices, and these calculations are performed without any truncation.

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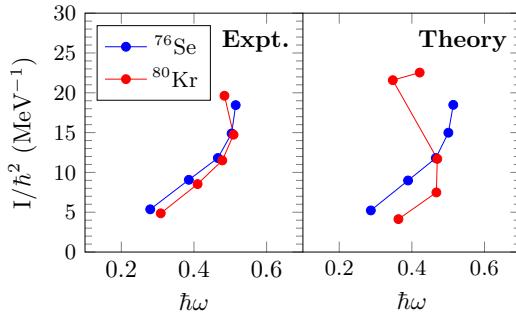


FIG. 2: Comparison of the theoretical and experimental kinematic moment of inertia (I/\hbar^2) as a function of rotational frequency ($\hbar\omega$).

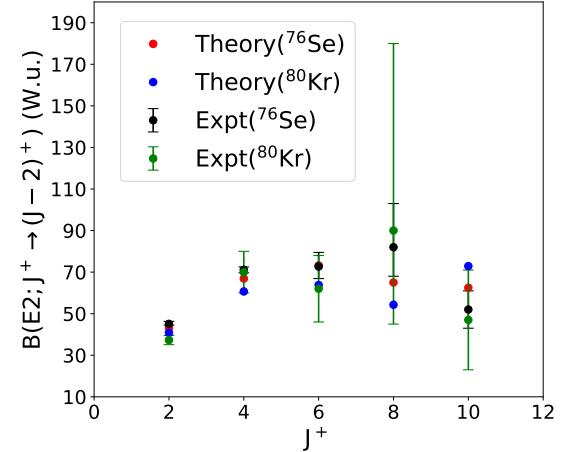


FIG. 3: Comparison of the shell-model predicted $B(E2)$ transitions in the pseudo-mirror nuclei ^{76}Se and ^{80}Kr with the experimental data.

Results and discussion

In this section, we discuss the structural properties of the pseudo-mirror nuclei ^{76}Se and ^{80}Kr . Figure 1 shows the comparison of the shell-model predicted yrast states of the ground state (g.s.) bands in both nuclei with the experimental data. The variation of the (I/\hbar^2) with respect to the rotational frequency ($\hbar\omega$) is illustrated in Fig. 2 using the relation $I/\hbar^2 = (2J-1)/E_\gamma(J \rightarrow J-2)$, where E_γ is the energy difference of two consecutive states of g.s. band. The rotational frequency and E_γ follow the relation, $E_\gamma = 2\hbar\omega$. Shell-model obtained $B(E2)$ transitions corresponding to effective charges ($e_p = 1.7, e_n = 1.1$) are compared with the experimental data in Fig. 3.

In the $f_{5/2}p_{9/2}$ model space, the pseudo-mirror nuclei ^{76}Se and ^{80}Kr have $N_p \times N_n = 48$, with $6p$ - $8h$ and $8p$ - $6h$ configurations, respectively. Our calculations show remarkable agreement with the experimental energy levels of both nuclei. In ^{76}Se , the configurations of $0^+ - 10^+$ states are predominantly keep four neutrons in the $\nu(g_{9/2})$ orbital, with no proton excitations in the $\pi(g_{9/2})$ orbital from the $f_{5/2}$ - p shells. In contrast, for ^{80}Kr , the dominant configurations of the $0^+ - 10^+$ states involve six neutrons in the $\nu(g_{9/2})$ orbital, with two proton excitation in the $\pi(g_{9/2})$ orbital from the 2^+ state and onward. The I/\hbar^2 trend is accurately reproduced for ^{76}Se , though a deviation is observed for ^{80}Kr , where shell-model calculations show back-bending at the

$8^+ \rightarrow 6^+$ transition, rather than at $10^+ \rightarrow 8^+$. This discrepancy stems from slight deviations between the shell-model predicted states and the corresponding experimental levels. Furthermore, similar $B(E2)$ transitions in analogous states of ^{76}Se and ^{80}Kr are reflected in both the experimental data and the shell-model results. In conclusion, the utilized effective interaction successfully reproduces most spectroscopic properties of both nuclei but requires further refinement for more accurate predictions of the I/\hbar^2 values for ^{80}Kr .

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