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 multiplates [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 ($\mathrm{I}/\hbar^2$). 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:

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

where, $\alpha = \{nljt\}$ denotes the single-particle orbitals and ε_α stand for the corresponding single-particle energies. $\hat{N}_\alpha = \sum_{j_z,t_z} a^\dagger_{\alpha,j_z,t_z} a_{\alpha,j_z,t_z}$ 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. $O^\dagger_{JT}$, and O_{JT} represent the fermion pair creation and annihilation operators, respectively.

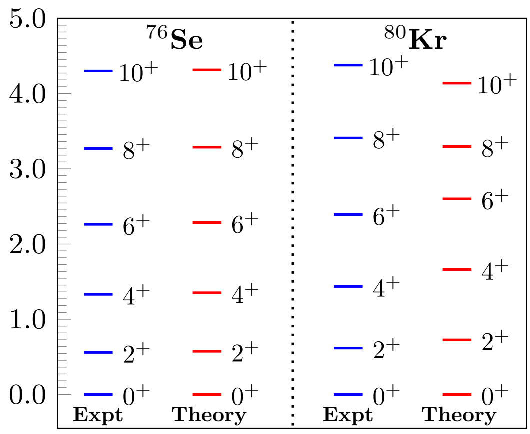

FIG. 1: Comparison of the shell-model predicted states of g.s. bands in the pseudo-mirror nuclei ^{76}Se and ^{80}Kr with the experimental data [5].

The mean-field part of the shell-model Hamiltonian corresponding to the jun45 interaction consists of $0f_{5/2}1p0g_{9/2}$ 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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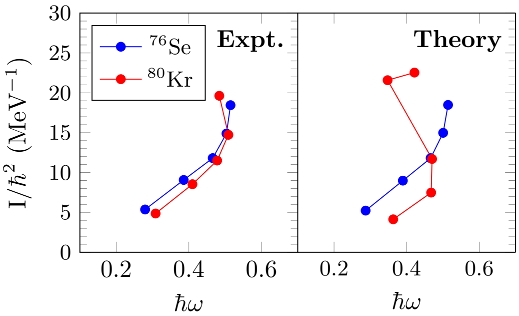

FIG. 2: Comparison of the theoretical and experimental kinematic moment of inertia ($I/\hbar^2$) as a function of rotational frequency ($\hbar\omega$).

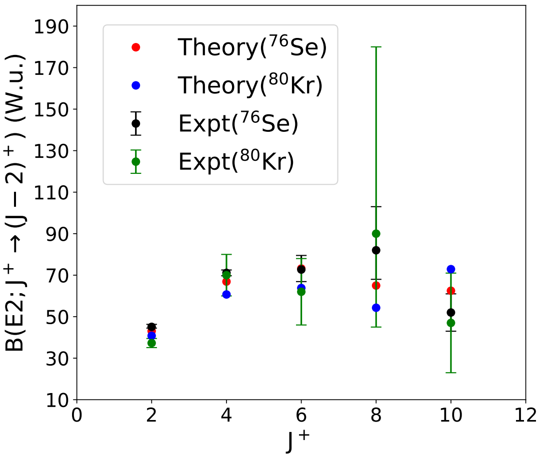

FIG. 3: Comparison of the shell-model predicted $B(E2)$ transitions in the pseudo-mirror nuclei ^{76}Se and ^{80}Kr with the experimental data.

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 $I/\hbar^2 = (2J-1)/E_\gamma(J \to J-2)$, 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 $f_{5/2}pg_{9/2}$ 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 $8^+ \to 6^+$ transition, rather than at $10^+ \to 8^+$. 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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