Shell-model study for the structure and isomeric state of ^{204}Po

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Introduction

The shell model study for the description of the multi-particle systems has been a successful approach for explaining the diverse structure of nuclei in the Segre chart. In the vicinity of doubly-magic ^{208}Pb, the shell model performs well in explaining the structure of many neutron-rich nuclei. The ^{208}Pb region provides an opportunity to observe and study complex nuclear structures with a tremendous amount of information to qualitatively improve the theoretical predictions. For example, the shape coexistence probed by α-decay observed in nuclei around Pb [1], the unique shape staggering observed in the mercury isotopes [2] which describes the concurrence of single-particle and collective degrees of freedom. While the experimental study of $^{192-210,216,218}$Po [3] isotopes concluded that with two extra protons after $Z = 82$, these nuclei exhibit a slow emergence of deformation, not showing any static deformation. According to many theoretical and experimental studies, Polonium is a unique testing ground to study both the spherical and deformed properties at different excitation energies.

To understand the nuclear structure, many experiments in the Pb region are being done at RIKEN, GSI/FAIR, and CERN to measure energy levels and electromagnetic properties. In this regard, we have performed systematic calculations for the ^{204}Po isotope to support the experimental results and to predict where experimental data is unavailable. A detailed discussion will be presented during the symposium.

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Theoretical Framework

The shell model Hamiltonian can be written in terms of single-particle energies and two-body matrix elements numerically,

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

where $\alpha = \{nljt\}$ denote the single-particle orbitals and ε_α is 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. $\langle j_\alpha j_\beta | V | j_\gamma j_\delta \rangle_{JT}$ are the two-body matrix elements coupled to good spin J and isospin T. A_{JT} and $A^{\dagger}_{JT}$ are the fermion pair annihilation and creation operators, respectively.

We have used KHH7B interaction in our study and diagonalized matrices using shell model code NuShellX. The KHH7B [4] interaction consists of the four proton orbitals $1d_{5/2}$, $1d_{3/2}$, $2s_{1/2}$, $0h_{11/2}$ below and three orbitals $0h_{9/2}$, $1f_{7/2}$, $0i_{13/2}$ above the $Z = 82$, and four neutron orbitals $1f_{5/2}$, $2p_{3/2}$, $2p_{1/2}$, $0i_{13/2}$ below and three orbitals $1g_{9/2}$, $0i_{11/2}$, $0j_{15/2}$ above $N = 126$ energy gap. In KHH7B interaction, the cross shell two-body matrix elements (TBMEs) were generated by the G-matrix potential (H7B)[5], while the proton-neutron, hole-hole, and particle-particle TBMEs are taken from Kuo-Herling interaction [6]. Due to huge-dimension, we have applied appropriate truncation in our calculation by allowing protons to occupy beyond $Z = 82$ and neutrons below $N = 126$.

Results and Discussion

In this section, the results of our calculations for the ^{204}Po isotope are presented and

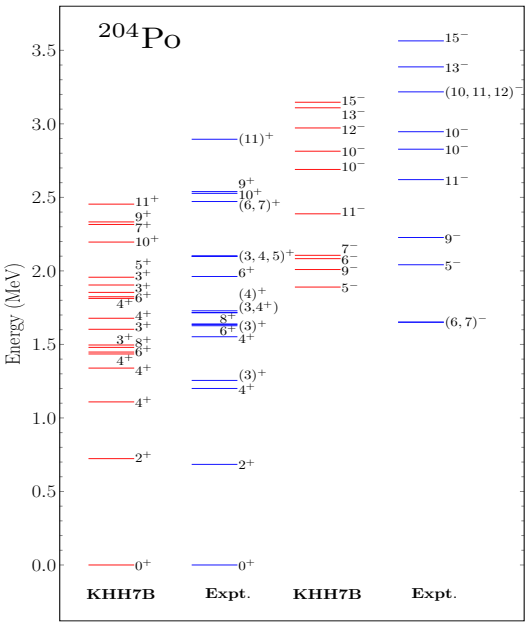

FIG. 1: Comparison between calculated and experimental energy levels [7] for ^{204}Po.

compared with the experimental data in Fig. 1. In this figure, observed levels up to 3.8 MeV excitation energy are reported. We have reported only those yrast and non-yrast states corresponding to experimental levels. Experimentally at 2.100 MeV the degenerate states $(3_3,4_5,5_1)^+$ are observed but theoretically we get non-degenerate 3_3^+ ,4_5^+ and 5_1^+ states at 1.854, 1.813 and 1.957 MeV, respectively. We observe that the 5_1^+ state lies 141 keV below the experimental energy. So we can suggest that the experimental state at 2.100 MeV corresponds to the 5_1^+. Our shell-model results corresponding to high-lying states are slightly compressed. It could be that the description of high-lying states requires core- excitation and some mixing between the single particle states and core excitation above Z=82 and N=126 shell closure. We found the yrast 0^+, 2^+ and 6^+ states coming from $\pi h_{9/2}^2$ configuration, with probabilities 23.13, 23.66 and 29.79%, respectively. The well-known isomeric state 8^+ with half-life 154 ns arises from the configuration $\pi h_{9/2}^2$. The negative-parity isomeric states 9^- and 15^- (with half-life 15.6 ns and 11.5 ns, respectively) are arising from the configuration $\pi h_{9/2}^2 \nu f_{5/2}^3 i_{13/2}^{-1}$ with 33% and 50% probabilities. These isomeric states are also compressed in our calculation.

We have calculated B(E2;$2^+ \rightarrow 0^+$) value, which is equal to 5.5 W.u., and experimentally it is found to be $\geq$ 8.7 W.u.[7]. The calculated quadrupole moment and magnetic moment for the 2^+ state are 0.2023 eb and 0.766 μ_N, respectively.

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