Mapping E2 strength and the Status of Vibrational Structure in ^{106}Pd

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Introduction

For a complete description of vibrational structure in nuclei, one should expect to observe multi-phonon (at least two and three-phonon) excitations. Recent measurements on the low-lying level structures of Cd [1] and Ni [2] isotopes, which had long been considered to be the best examples of spherical vibrators, are suggestive of serious deviation from the expected vibrational picture for the two- and three-phonon states. As a part of our continuing effort to search for the possible existence of multi-phonon vibrational structure, it is interesting to investigate the level structure of the Pd nuclei. With the aim of obtaining a comprehensive picture of the properties of low-spin levels in ^{106}Pd, a series of γ-ray spectroscopic experiments has been performed with the $(n,n'\gamma)$ reaction.

Experimental Technique

The experiments were carried out at the University of Kentucky Accelerator Laboratory, where nearly mono-energetic neutrons, produced via the ^{3}H$(p,n)^3$He reaction with pulsed and time-bunched beams of protons, bombarded a 19.98-g sample of Pd metal powder, enriched to 98.53% in ^{106}Pd. Gamma rays produced by inelastic neutron scattering were detected with a Compton-suppressed HPGe detector. By varying the neutron energy in steps of 100 keV (with an energy spread typically of about 60 keV) between 2.0 and 3.8 MeV, γ-ray excitation functions were obtained with the detector placed at 90° with respect to the beam. Angular distributions of γ rays were obtained at neutron energies of 2.2, 2.7, and 3.5 MeV, where the detector was positioned at angles between 40° and 150°. Level lifetimes (within the femtosecond regime), γ-ray branchings, and mixing ratios were determined from the angular distribution data. A γ-γ coincidence measurement was carried out at a neutron bombarding energy of 3.3 MeV, with 4 HPGe detectors placed $\sim$ 6 cm from the sample.

Experimental Results

A simplified view of the low-lying level structure of ^{106}Pd is shown in Fig. 1. The observed $E2$ decay strengths are compared with the predictions of the harmonic vibrator model. Near degeneracy of the triplet of states at $0^+(1134)$, $2^+(1128)$, and $4^+(1229)$ with

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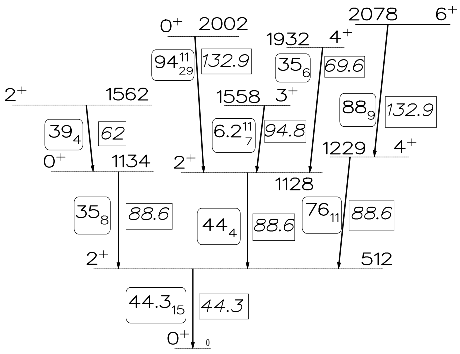

FIG. 1: Comparison of the low-lying level structure of ^{106}Pd with the prediction from harmonic quadrupole vibrator model. The level energies (experimental) are in keV; whereas the $B(E2)$ strengths are in W.u. The experimental $B(E2)$ values are placed within rounded rectangular boxes; whereas the expected corresponding strengths from the vibrator model are placed within rectangular boxes.

their enhanced $E2$ decay strengths suggest the two-phonon nature for these states and the vibrational degrees of freedom may be important for the description of the low-lying level structure of ^{106}Pd. Only the expected dominant transitions from the so-called "three-phonon" states to the two-phonon states are shown. It is obvious that the three-phonon to two-phonon $E2$ decay strengths for the $2^+(1562)$, $3^+(1558)$, and $4^+(1932)$ states are deficient with respect to the harmonic quadrupole vibrational pattern. If we consider that the deficiency is due to the result of "anharmonicity" that fragments the expected strength, causing it to appear in other higher-lying 2^+, 3^+, and 4^+ states, then it is important to identify the $E2$ strength from as many higher-lying 2^+, 3^+, and 4^+ states as possible to the two-phonon states. As is shown in Fig. 2, a deficit in $E2$ strength exists in all cases, except possibly for the $\Sigma 2^+ \rightarrow 2^+_{2ph}$ transition. For the decay from the 3^+ states to the two-phonon states, the observed deficiency (not shown in Fig. 2) is about four times in comparison to the vibrator model prediction.

Thus, we must conclude that fragmentation into high-lying states cannot account for the observed deficiency. The results presented here raise a question about the nature of the

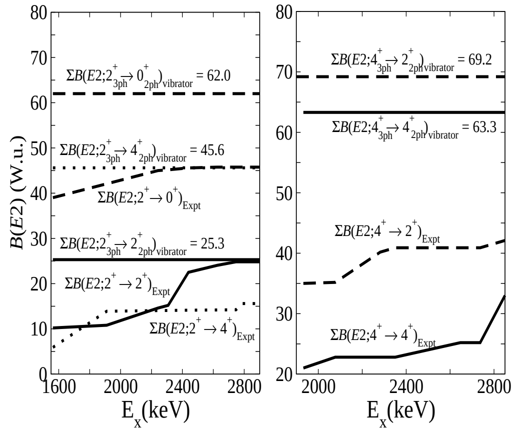

FIG. 2: Running sum of observed E2 decay strengths for all the transitions decaying from the states with 2^+ (left panel) and 4^+ (right panel) spins, up to $E_x \sim 3$ MeV, to the two-phonon triplet of states. The expected upper limits for the corresponding transitions following the prediction from the harmonic vibrator model are shown as horizontal lines for comparison.

vibrational quadrupole behavior in ^{106}Pd. Examining the levels studied in this work and their connections to other levels might lead to the observation of rotational structure in ^{106}Pd, similar to what has recently been found in the neighboring Cd-isotopes[1].

Acknowledgments

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References

[1] P.E. Garrett and J.L. Wood, J. Phys. G: Nucl. Part. Phys. **37**, 064028 (2010).

[2] A. Chakraborty *et al.*, Phys. Rev. C **83** 034316 (2011).