Low-lying Band Structure and the Onset of Octupole Collectivity in ^{150}Nd

A. Chakraborty[1,2,3],* F.M. Prados-Estévez[2,3], S.N. Choudry[2], B.P. Crider[2,3], P.E. Garrett[4], W.D. Kulp[5], A. Kumar[2,3], M.T. McEllistrem[2], S. Mukhopadhyay[2], M.G. Mynk[3], J.N. Orce[2,6], E.E. Peters[3], J.L. Wood[5], and S.W. Yates[2,3]

[1] *Department of Physics, Krishnath College, Berhampore, Murshidabad, West Bengal -742101, INDIA*
[2] *Department of Physics and Astronomy, University of Kentucky, Lexington, Kentucky 40506-0055, USA*
[3] *Department of Chemistry, University of Kentucky, Lexington, Kentucky 40506-0055, USA*
[4] *Department of Physics, University of Guelph, Guelph, Ontario, N1G2W1, Canada*
[5] *Department of Physics, Georgia Institute of Technology, Atlanta, Georgia 30332-0430, USA and*
[6] *Department of Physics, University of the Western Cape, P/B X17, Bellville, ZA-7535, South Africa*

Introduction

Lying in a transitional region, the nucleus ^{150}Nd is surprisingly poorly studied in comparison to the other neighboring isotones, such as ^{152}Sm and ^{154}Gd. There are serious discrepancies in the published work for states in ^{150}Nd above 1150 keV in excitation. Also, a leading issue for the stable N=90 isotones is whether they are a manifestation of a critical-point phase transition [1] or shape co-existence [2]. A complete knowledge of the low-lying non-yrast states often plays a vital role in differentiating one phenomenon from the other. Thus, with the aim of obtaining a comprehensive picture of the properties of low-spin levels in ^{150}Nd, a series of γ-ray spectroscopic experiments involving measurements of excitation functions, angular distributions, and $\gamma-\gamma$ coincidences have been performed using the $(n,n'\gamma)$ reaction.

Experimental Procedure

The experiments were carried out at the University of Kentucky Accelerator Laboratory, where nearly monoenergetic neutrons, produced via the ^{3}H$(p,n)^{3}$He reaction with pulsed and time-bunched beams of protons, bombarded a 31.15-g sample of Nd_2O_3 enriched to 96.17% in ^{150}Nd. Gamma rays produced by inelastic neutron scattering were detected with a single Compton-suppressed HPGe detector. By varying the neutron energy in steps of 100 keV (with an energy spread typically of about 60 keV) between 1.2 and 3.0 MeV, γ-ray excitation functions were obtained with the detector placed at 125° with respect to the proton beam, which was incident on the tritium gas target. Angular distributions of γ rays were obtained at neutron energies of 1.2, 1.4, 2.05, and 2.7 MeV, where the detector was rotated through angles between 40° and 155°. A γ-γ coincidence measurement was carried out at a neutron bombarding energy of 3.2 MeV, with 4 HPGe detectors placed $\sim$ 5 cm from the ^{150}Nd sample. The lifetime of a particular level was determined by considering the Doppler shifts of the γ ray(s) decaying from the level as a function of emission angle, using the methodology described in Ref.[3]. The shifts in transition energies of the γ rays decaying from the 853-keV level as a function of angle is demonstrated in Fig. 1.

*Electronic address: anagha.chakraborty@gmail.com

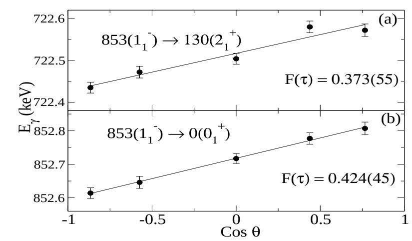

FIG. 1: The angle-dependent shift in energy of the 723- and 853-keV γ rays from the 853-keV level. From the measured shift, the experimental F(τ) values for the two transitions were obtained. The weighted average F(τ) value was projected on the theoretical F(τ) vs τ curve, and a lifetime value of 66^{+10}_{-8} fs for the 853-keV level was obtained.

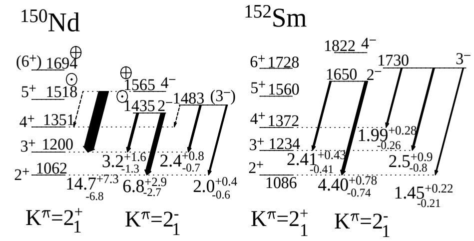

FIG. 3: Comparison of $B(E1)$ values for the transitions between the levels of the K^π=2_1^- and K^π=2_1^+ bands of ^{150}Nd (left) and ^{152}Sm (right). See the caption of Fig. 2 for additional details. Newly established levels and newly assigned spins for the existing levels are marked with ⊕ and ⊙, respectively.

Experimental Results

Figs. 2 and 3 illustrate the $E1$ decays for the transitions in ^{150}Nd. The $E1$ decays for the corresponding levels in ^{152}Sm are also shown in the figures for comparison. From the enhanced $E1$ decay rates for the transitions shown in Fig. 2, it is quite obvious that the yrast octupole K^π=0_1^- band is built on the ground-state band in both ^{150}Nd and ^{152}Sm.

We also report here another feature associated with octupole bands in ^{150}Nd and ^{152}Sm, namely the unusually fast $E1$ transitions seen between a $K^\pi = 2^-$ band and the lowest $K^\pi = 2^+$ band (see Fig. 3). The large $E1$ transition rates between a $K^\pi = 2^-$ and a $K^\pi = 2^+$ band are, to our knowledge, unprecedented beyond the instances in ^{150}Nd and ^{152}Sm. Such a feature of nuclear structure has not been predicted, as far as we know, and is certainly absent from the recent theoretical descriptions of collective octupole states in nuclei.

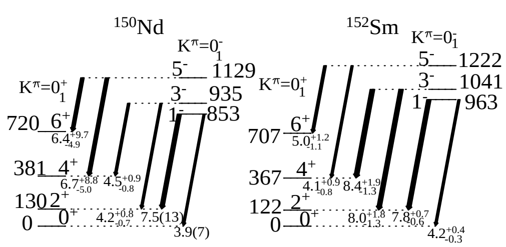

FIG. 2: Comparison of $B(E1)$ values (in mW.u.=10^{-3} W.u.) for the transitions between the levels of the K^π=0_1^- and K^π=0_1^+ bands of ^{150}Nd (left) and ^{152}Sm (right). The widths of the arrows are proportional to the central $B(E1)$ values of the corresponding transitions. The $B(E1)$ values with the associated uncertainties for the corresponding decays are shown at the bottom of the arrows.

It is worthwhile mentioning that a simple coupling of an octupole degree of freedom (K^π = 0^-, 1^-, 2^-, or 3^-) to a γ vibration (K^π = 2^+) would result in a range of possible K-bands (K = 2; 1,3; 0,4; 1,5). The operation of a $\Delta K = 0, \pm1$ selection rule for $E1$ transitions would favor the decay pattern $K^\pi = 2^- \rightarrow K^\pi = 2^+$ observed. However, we know of no prediction, or expectation, that the structure reported here should be a systematic feature of nuclei in this (or any other) region.

Acknowledgments

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References

[1] P. Cejnar, J. Jolie, and R. F. Casten, Rev. Mod. Phys. **82**, 2155 (2010).
[2] K. Heyde and J. L. Wood, Rev. Mod. Phys. **83**, 1467 (2011).
[3] T. Belgya, G. Molnár, and S.W. Yates, Nucl. Phys. **A607**, 43 (1996).