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Lifetime measurements of octupole excitations in ^{168}Yb

S. Pascu (Spokesperson), V. Derya, J. Endres, M. Elvers, F. Schlüter, A. Zilges

Institut für Kernphysik, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany

D. Bucurescu, I. Căta-Danil, D. Deleanu, D. Filipescu, D. G. Ghiţă, T. Glodariu, C. Mihai, N. Mărginean, R. Mărginean, A. Negreţ, T. Sava, L. Stroe, N. V. Zamfir

"Horia Hulubei" National Institute for Physics and Nuclear Engineering, R-76900, Bucharest-Măgurele, Romania

Gh. Căta-Danil

Politehnica University of Bucharest, 060042, Bucharest, Romania

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1. Experiment Summary

We propose to measure the lifetimes of the first excited 3^- and 5^- states in ^{168}Yb using the fast timing method with the Bucharest HPGe and $LaBr_3$:Ce detector array. In order to populate the excited states in the ^{168}Yb residual nucleus we will use the reaction ^{166}Er(α,2nγ)^{168}Yb. The incident energy of the α particles will be E_α=24 MeV. The aim of this measurement is the determination of the absolute E1 transition strengths for the first negative parity states. The increased E1 strengths in the rare-earth region are a current topic of numerous theoretical works, which needs to be confronted with robust experimental observables. We will also be able to extract the dipole moment of the octupole vibrations, which can be compared to theoretical estimates using different empirical parameterization.

2. Introduction

The existence of stable quadrupole deformed nuclear shapes with axial symmetry in the intrinsic frame has been known for a long time. The presence of the negative parity states within the low-lying levels of the even-even nuclei led to the suggestion that they constitute evidences for octupole vibration or deformation [1].

In a microscopic picture, the origin of octupole collectivity can be explained by the interplay of the unique parity orbit in each major shell and a common parity orbit that differ by angular momentum and total spin $\Delta l = \Delta j = 3$. Octupole correlations are strongest when the Fermi surface lies between those orbits and the octupole operator has a maximum contribution.

In a macroscopic picture, the octupole excitations and their coupling can be described as phonon excitations and especially two phonon excitations have been investigated in the last years [2,3]. A prominent example of a two-phonon excitation is the coupling of a quadrupole ($J^{\pi} = 2^{+}$) and an octupole ($J^{\pi} = 3^{-}$) phonon. In the harmonic phonon model, they form a degenerate multiplet ($2^{+}\otimes 3^{-}$) with spin and parities $J^{\pi} = (1^{-}\text{-}5^{-})$ at the summed energy of both excitations. Due to anharmonicity effects, the degeneracy is in general broken.

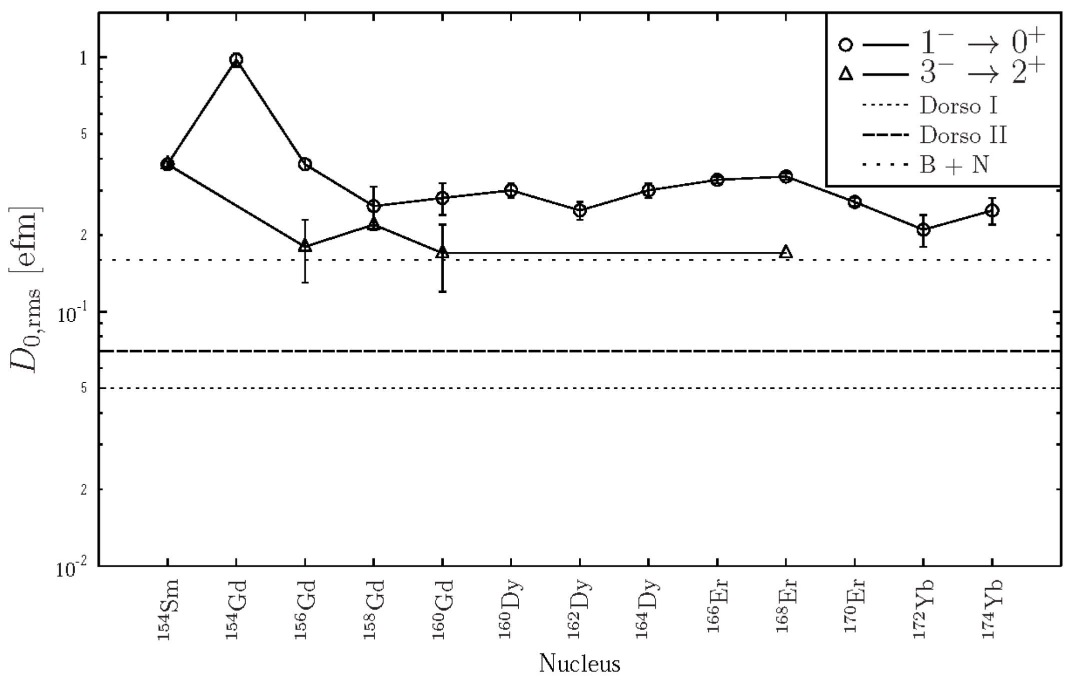

Figure 1: Dipole moments for $J^{\pi} = 1^{-}$ and $J^{\pi} = 3^{-}$ states in the $K^{\pi} = 0^{-}$ band. The new experimental data for the 1^{-} and 3^{-} states are listed in [8-11]. All other data as well as the theoretical predictions are compiled in [7]. The B+N parameterization for the dipole moments of the 3^{-} states is in good agreement with most of the experimental values, while the moments for the 1^{-} states are underestimated for all nuclei.

In a picture where octupole-vibrational states are described as an octupole phonon coupled to a spheroidal nucleus, only the electric transitions E2 and E3 are allowed for a decay in a one step process. However, one interesting aspect of octupole states in the rare-earth region are the relatively strong E1 transitions with intensities that are often in the order of 10^{-3} W.u. In order to explain this phenomenon, two different approaches were developed. The first ansatz which was suggested by Bohr and Mottelson is a macroscopic approach based on the liquid drop model where a dipole moment is induced by electrostatic effects [4]. In a nucleus having both a quadrupole and an octupole deformation, the protons tend to concentrate at points with high curvature. Hence, the centre of mass and charge differ, so that a dipole moment is induced. The experimental values and the theoretical predictions for the dipole moment are compared using three different empirically obtained parameterizations Dorso I, Dorso II and B+N [5,6,7] which is shown in Fig.1. The first parameterization was determined by fitting atomic masses and fission barriers in the region from ^{64}Zn to ^{206}Pb while the second one was obtained from a different data set. The last parameterization (B+N) was introduced by Butler and Nazarewicz where the neutron skin contribution was corrected to obtain positive dipole moments for all nuclei. All theoretical values were taken from [7] and the experimental data, also taken from [7] was supplemented by more recent data [8-11].

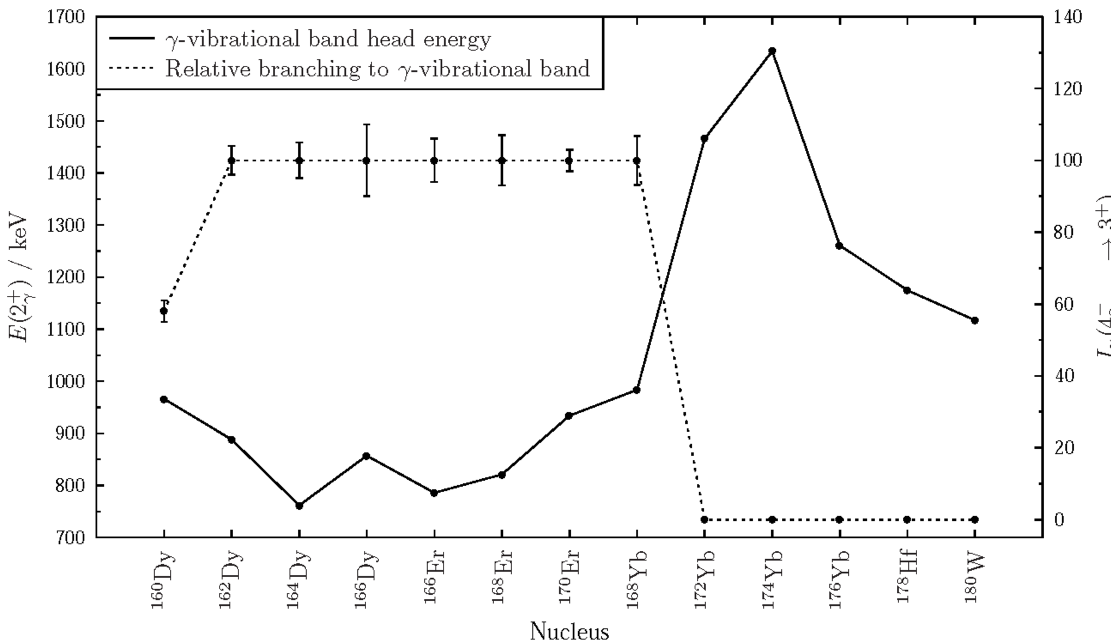

Figure 2: Systematic behaviour of the octupole-vibrational states decaying into the γ-vibrational band. The strong decay of the $J^\pi = 4^-$ state to the $J^\pi = 3^+$ stops abruptly between ^{168}Yb and ^{172}Yb (right y-axis) while at this point the band-head energy of the γ-vibrational band increases (left y-axis).

The dipole moments of $J^\pi = 1^-$ states are strongly underestimated for both the data available in the last comparison and for ^{154}Gd [8]. Thus, the liquid drop model is insufficient to describe these experimental data.

For the $J^\pi = 3^-$ state, only the dipole moments for ^{154}Sm and ^{160}Gd were investigated in [7] which could be extended by two Gadolinium isotopes and ^{168}Er [9,10]. The B+N parametrisation and the experimental data agree within the error margins for the nuclei ^{156,160}Gd and ^{168}Er. Furthermore, the disagreement for the remaining data points is much less than for the $J^\pi = 1^-$ states. However, additional data are needed especially for A>160 nuclei, to conclude if the macroscopic model is capable to describe the E1 transition strengths of the $J^\pi=3^-$ states in the majority of the nuclei.

In order to explain the discrepancy between the experimental data and the theoretical predictions, it was proposed that the $J^\pi = 1^-$ states weakly mix with the GDR [12,13].

Furthermore, if a coupling to the GDR is assumed, members of the $K^\pi = 1^-$ band can also decay to the γ-vibrational band. This kind of systematics is pursued in Fig. 2 which shows that the band-head energies of the γ-vibrational band are less than 1 MeV for A<168 while the band-head energies increase in average by more than 300 keV for A>168 which can be explained by a change of the dominant Nilsson orbits. Obviously, the wave function of the first configuration shows a stronger mixing with the octupole-vibrational band and therefore strong decays are observed while for the second configuration the mixing is rather weak.

Additional informations are needed in order to complete these two systematics and to decide in favor of one interpretation or the other.

3. Experiment Description

We propose to perform the ^{166}Er(α,2nγ)^{168}Yb reaction to study the lifetimes of the first 3^- and 5^- states in ^{168}Yb using the fast timing method described in [14]. The incident energy of the α particles will be E_α=24 MeV. These lifetimes are estimated to be of the order of a few hundred picoseconds. Besides measuring the lifetimes for these two states, we anticipate that at least 4 additional states will have a lifetime in the nanosecond range. All the estimations are based on systematic studies of the excited states in neighboring isotopes and also on the prediction made within IBA-spdf. These two points of view (experimental and theoretical) predict that the 4^+ state in the yrast band will have a lifetime of approximately 0.1 ns, while three other states from the γ-vibrational band (2^+, 3^+ and 4^+) are predicted with a lifetime of more than 1 ns.

The cross section for this reaction is estimated to be σ~600 mb. The nucleus ^{168}Yb will be produced by bombarding a target of ^{166}Er of 2 mg/cm^2 thickness with 24 MeV α particles. The target material will be provided and prepared by the University of Cologne. The minimum intensity of the required beam is 5 nA. Taking into account an estimated HPGe efficiency of 1% and an average $LaBr_3$:Ce efficiency of 1%, we expect approximately 450 triple coincidences per hour. Therefore we request 10 days (30 shifts) of beam time. In addition, we will need another two days for calibration purposes.

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