Lifetime measurements in the γ band of ^{160}Er nuclei

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Abstract

We propose to measure electromagnetic transition probabilities in the γ band of ^{160}Er. The states will be populated in the fusion-evaporation reaction ^{152}Eu (^{11}B, 4n) at beam energy of 50 MeV. We intend to use the Bucharest plunger device in order to measure the lifetimes of the states in γ band via the Recoil Distance Doppler-Shift Method (RDDSM).

1. Scientific motivation

The study of phase transitions in mesoscopic systems, such as atomic nuclei, molecules or atomic clusters is a topic of interest in current physics research [1]. Critical-point symmetries [2,3] which describe nuclei at points of phase/shape transitions between the symmetry limits of IBM-1 [1,4] attract considerable attention, since they yield parameter independent solutions (up to scale factors) which are found to be in a good agreement with experiment [5, 6]. The critical-point symmetries are analytical solutions of the differential equations associated with the Bohr Hamiltonian [7]. An analytical solution of the Bohr Hamiltonian which is appropriate to the critical point between the spherical limit (U(5)) and axially deformed limit (SU(3)), is called X(5) symmetry [3]. The first nucleus identified as exhibiting X(5) behavior was ^{152}Sm [6], followed by ^{150}Nd [8]. Further experiments on ^{152}Sm [9–11] and ^{150}Nd [11, 12] support this conclusion. An open problem that remains is how to treat simultaneously the ground state,   and   excitations.

Beyond the transitional point X(5) with an $R_{4/2}$= 2.9 ($R_{4/2}$ = E_4^+/E_2^+) deformed nuclei rapidly evolve into almost rigidly rotating bodies with $R_{4/2}$ values close to 3.33. The rigid rotor limit, however can hardly be reached. Deformed nuclei typically exhibit $R_{4/2}$ values between 3.2 and 3.32 while very few deformed nuclei have $R_{4/2}$ values between 2.9 and 3.2. In order to describe the collective behavior of such nuclei the X(5) model has been generalized in terms of the Confined -Soft (CBS) rotor model [13, 14]. Similar to the X(5) model, the CBS rotor model considers a square-well potential, however, with the inner potential boundary shifted away from =0. Alike X(5), the CBS rotor model is analytically solvable in terms of Bessel functions and it is based on the phenomenon of intrinsic excitations and centrifugal stretching in a soft potential. It has been demonstrated that this model have a remarkable capability for quantitatively describing the evolution of excitation energies of rotational bands in deformed nuclei [15, 16].

The nucleus ^{160}Er (a partial level scheme of ^{160}Er is shown in Fig. 1), which has $R_{4/2}$ = 3.1 lies on the transition path between the critical point of the vibrator-rotor shape phase transition, X (5) [3], and the rigid rotor limit, SU (3) (spherical vibrator ($R_{4/2}$ = 2.0) to rigid rotor ($R_{4/2}$ = 3.33)). The measured X ($E0/E2$; 0^+_2 0^+_1) ratio indicates that this nucleus is located rather close to the X(5) critical point [17] (the same can be seen in the evolution of the energy in the ground band – see Fig. 2).

On the contrary the $R_{4/2}$ ratio and the B(E2;I→I-2)/B(E2;2$^+$) ratios (see Fig. 3) indicate that the ^{160}Er nucleus is closer to the rotor than to X(5) point. Therefore ^{160}Er has been studied in the frame of CBS model [16].

Quantitative agreement is seen between level energies in the ground-state and -vibrational bands. It is seen that the CBS rotor model has considerable success in describing the relative energy levels of all the low-lying quadrupole collective structures in ^{160}Er, with the largest inconsistencies being the incorrect scale in the prediction of the energy levels in the   band and in the staggering that occurs in the -band. The CBS-model

results qualitatively agree with the data for interband to intraband *E*2 branching ratios for the 7^+, 5^+, and 4^+ states in the γ-band within a factor of about 2. A larger deviation is seen only for the 6^+ state. Evidently there is a problem in the CBS-model, similar to the one in the X(5) model – both of them experience difficulties in reproducing the energy levels pattern and the branching ratios in the -band. Conversely, the IBM reproduces the data on the -band branching ratios in ^{160}Er [16] remarkably well with the largest deviation for the 4^+ state. This makes an (extremely) intriguing case to check whether CBS and IBM can reproduce the absolute transition strengths in the -band of ^{160}Er.

The measurement of the lifetimes inside the -band of ^{160}Er can help for better understanding of the discrepancies that arise in the explanation of the properties of the -band.

2. Experiment and preliminary calculations

Currently, there are no lifetime measurements of the γ-band in ^{160}Er. The goal of the present proposal is to measure precisely the lifetimes in the γ-band in ^{160}Er. According to calculations with the program PACE, cross-section of 470 mb is predicted for the 4n evaporation channel of the reaction ^{153}Eu (^{11}B, 4n) ^{160}Er at beam energy of 50 MeV. Two methods based on the Doppler-shift effect are widely used for the lifetime measurements- RDDSM for lifetimes in the picoseconds and (Doppler-shift Attenuation method) DSAM in the sub-picoseconds time range, respectively. In order to achieve the desired high precision and to eliminate the uncertainties related to the unobserved feeding, we intend to use the method described in Ref. [20] for the analysis of the line-shapes observed in the coincidence RDDSM measurements of nuclear lifetimes, in which a gate is set on a transition directly feeding the level of interest. This method of analysis includes the effect of emission during the slowing-down time of the ions in the stopper and is essential for the correct analysis of levels with lifetimes smaller than, or comparable to, the slowing-down time. The formalism for lifetime determination according to the Differential Decay-Curve Method (DDCM) [21] was further developed in order to take into account the Doppler-shift attenuation effects and the use of a gate which selects a specific velocity distribution from the total one. Additionally, two methods for the description of the line-shapes observed in the coincidence DSAM have also been proposed [22, 23]:

(a) The case when a gate is set on a transition that feeds directly the level of interest is considered in detail in Ref. [22] where the formalism for lifetime determination in the general framework of the DDCM is also developed.

(b) The case when a gate is set on the portion of the line-shape of a transition that depopulates the level of interest is considered Ref. [23]. This method accounts more precisely for the time-velocity correlations in comparison with previous work [24] and is characterized by an increased flexibility with respect to the position of the partial gate set on the depopulating transition.

Both methods are free, by their use in coincidence mode, of the long-standing problem of the unknown feeding of the investigated level and are therefore the most reliable approaches for analyzing coincidence RDDSM and DSAM data at present.

We have performed a Monte-Carlo simulation of the proposed experiment for ^{160}Er in order to optimize some details of the experimental setup.

The recoiling nuclei have a mean recoil velocity of about 0.7 % of the speed of light. For the determination of lifetimes of order of 1ps we have to take into account the effect of the slowing down of recoils in the stopper in order to successfully describe the line shapes of both the shifted and unshifted components.

Data analysis will be performed separately for the individual rings into which the Ge detectors of the spectrometer can be grouped.

We propose, therefore, an experiment using RDDSM and DSAM to measure lifetimes in the γ band of ^{160}Er and remeasure the life times in the yrast band. We plan to use the Bucharest plunger device for the RDDSM experiment.

Ten target-to-stopper distances between 10 and 300 μm will be measured.

For the RDDSM measurement, the targets will consist from a self-supporting isotope-enriched foil with a thickness of 0.6 mg/cm^2. We estimate that a beam time of 7 days (21 shifts) is required to carry out the proposed measurements.

Summary of the experimental details:

Reactions: ^{153}Eu (^{11}B, 4n) ^{160}Er
Beam Energy and Intensity: 50 MeV, 3-4 pnA
Target: self-supporting isotope-enriched foil ^{153}Eu with a thickness of 0.6 mg/cm^2
Stopper foil: 5.0 mg/cm^2 Pb
Mean recoils velocity: v/c ~ 0.7%
Plunger: Bucharest plunger apparatus

For measuring shorter lifetimes we need to do DSAM which will require 2 additional days (which are included in the total beam time request). The target for this measurement will be the same.

3. References

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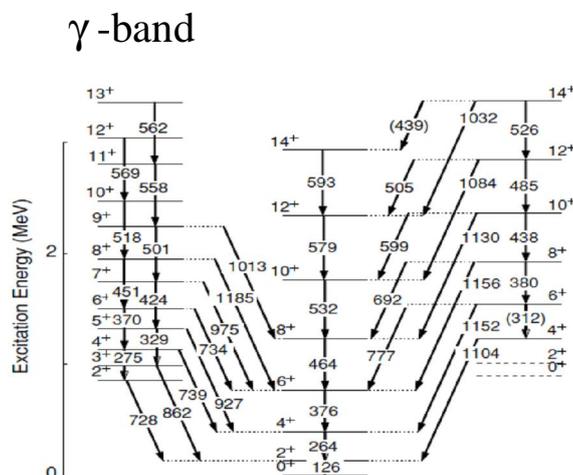24. F. Brandolini *et al.*, Nucl. Instrum. Methods Phys. Res. **A 417** (1998) 150.
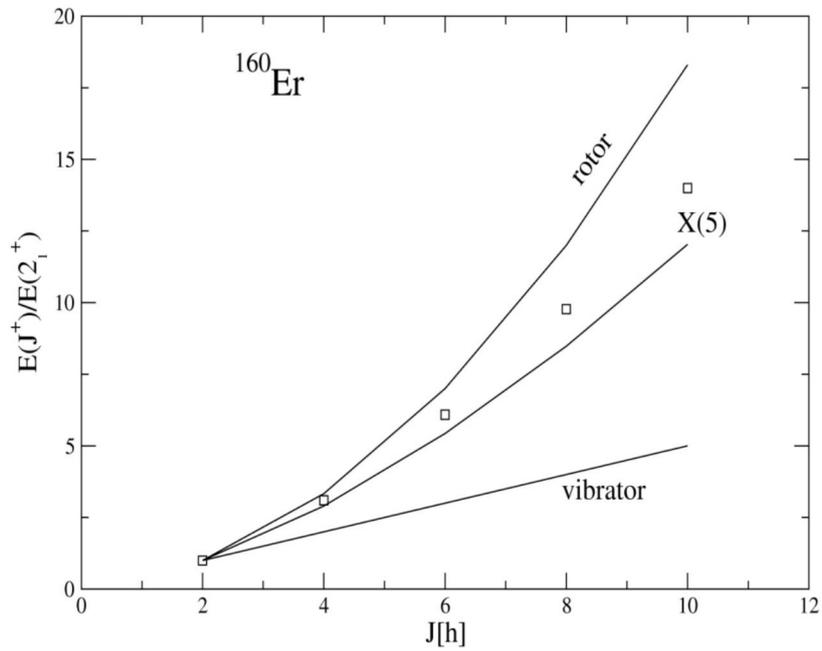
Fig.1 Partial level scheme of ^{160}Er.

Fig.2 Comparison between experimentally observed energy levels and those predicted for different theoretical approaches.
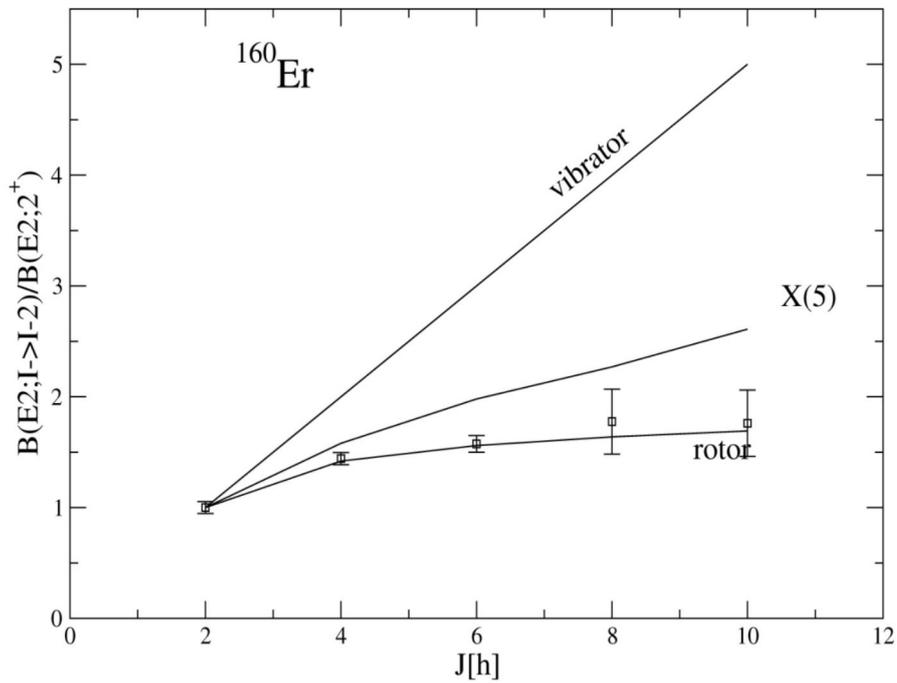

Fig.3 Comparison between B(E2; I → I-2)/B(E2;2$^+$) values and those predicted for different theoretical approaches.