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Lifetimes and electromagnetic transition strength in ^{157}Dy

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Lifetimes and electromagnetic transition strength in ^{157}Dy

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Abstract. Excited states in ^{157}Dy have been studied by γ-γ coincidence measurements via the reaction ^{124}Sn(^{36}S,3n) at a beam energy of 155MeV. Lifetimes of the relatively lower-spin states in ^{157}Dy were measured by means of the Recoil Distance Dopplershift technique in the coincidence mode. The experiment was performed at the Laboratori Nazionali di Legnaro with the GASP array and the Cologne plunger device. With the same setup a Doppler-shift attenuation (DSA) lifetime measurement was performed for the higher spin states. The Differential decay-curve method was applied for the lifetime determination.

1. Introduction

The $^{156-158}$Dy isotopes have neutron numbers between 90 and 92 and thus lie close to the onset of prolate deformations taking place around N = 88 in this mass region. From the known properties of the low-spin states of these nuclei it can be deduced that they are already rather well deformed. The β-deformations in ^{156}Dy is 0.29 which is slightly smaller than the deformation in the heaviest stable isotope ^{164}Dy $\beta = 0.35$ close to midshell. The structure of the energy levels in these nuclei has been study in detail in the past [1, 2, 3, 4, 5, 6, 7]. An IBA fit [9] helps to position ^{156}Dy in the transitional region between spherical and deformed nuclei. The results of the fit and empirical considerations reveal that in ^{156}Dy the gamma-degree of freedom (or the triaxiality) plays a more important role than in the established X(5) nuclei ^{152}Sm,^{150}Nd and ^{154}Gd. A fit of the data using the General Collective Model points to a deeper collective potential V (β,γ) in ^{156}Dy which may be also a reason for the differences in the spectroscopic properties of ^{156}Dy and the neighboring N=90 isotones exhibiting an X(5) character. A recent work on ^{155}Dy [8] reveals that the different low-lying quasineutron bands are characterized by different quadrupole deformations. This may be explained by configuration dependent particle-core interaction in the transitional ^{155}Dy. At high spin, the new data for ^{155}Dy seem to confirm earlier findings of reduced E2 collectivity related to the phenomenon of band termination for some of the bands. Our study of ^{157}Dy allows to investigate if the shape-transition effects observed in neighboring lighter Dy isotopes continue gradually when going away from the N=82 shell closure towards midshel. In addition, by analyzing the data from our experiment we have the possibility to study the influence of the rotation alignment on the collective properties in ^{157}Dy. The entire set of E2-transition strengths deduced for ^{157}Dy will result in a systematic view of the collective behaviour of this nucleus with increasing rotational frequency and provide strong evidence for deformation changes.

2. Experimental details

The experiments were performed at the XTU Tandem Facility in Laboratori Nazionali di Legnaro, Italy. The excited states in ^{157}Dy were populated using the ^{124}Sn(^{36}S,3n)^{157}Dy reaction. For the RDDS part of the experiment the beam of ^{36}S was accelerated to an energy of 155 MeV and then delivered to the target consisting of 0.9 mg/cm^2 Tin, enriched to 97.7% in ^{124}Sn. The tin material was evaporated onto a backing of 1.8 mg/cm^2 Ta foil. To stop the recoils a 12.0 mg/cm^2 Au foil was used. The levels of interest for DSAM part of the experiment were populated using a beam energy of 145 MeV. A 0.9 mg/cm^2 Sn foil enriched to 95.3% in ^{124}Sn was used as a target. A 13.4 mg/cm^2 Ta foil was used as a backing to stop the recoils. The emitted γ-rays were detected by the GASP detector array [10]. The HpGe detectors from the GASP array are grouped in 7 rings with respect to the beam line. For our analysis four rings where appreciable Doppler-shifts can be observed were used, namely ring 0 (mean angle with respect to the beam axis of 34.6°), ring 1 (59.4°), ring 5 (120.6°) and ring 6 (145.4°). With the same setup we measured DSAM and RDDS lifetimes in ^{156,155}Dy and the results were published in Refs.[8, 9, 11, 12] where additional details on the experimental setup can be found.

3. Data analysis

The procedure described in [13] was used for analysis of RDDS data. This procedure represents a further extension of the Differential decay-curve method (DDCM) [14, 15]. This extennsion mainly concerns taking into account the velocity distribution of the recoils and the finite slowing-down time in the stopper in γ-γ coincidence. An example of such line-shape analysis and lifetime determination is shown on the l.h.s. of Fig. 1 where the Doppler-shift attenuated (DSA) fraction due to emissions during the slowing-down is also displayed. Separate contributions to the RDDS spectra are obtained when setting a gate on part of the "shifted" component of the feeding transition which result from the different possible combinations of the emission times of the feeding transition and depopulating transition. These contributions are disentangled by a fitting procedure whose details are given in Ref. [13].

The approach used for the analysis of the singles DSA line shapes and deriving lifetimes is presented in Refs. [15, 16]. For the description of the stopping process we used a modified version of the computer code DESASTOP [17, 18] by G. Winter. This newer version allows for a numerical treatment of the electron stopping powers at relatively higher ion energies.The gates were set on lower-lying transitions, that's why it turned out that some unknown or side-feeding is present at every investigated level. For this reason we adopted an often applied hypothesis on the time-behavior of the side-feeding, according to which it is the same as that of the known feeding. Additionally, we investigated the influence of the side-feeding on the results obtained for the lifetimes (cf. Eq.8 in Ref.[16]).

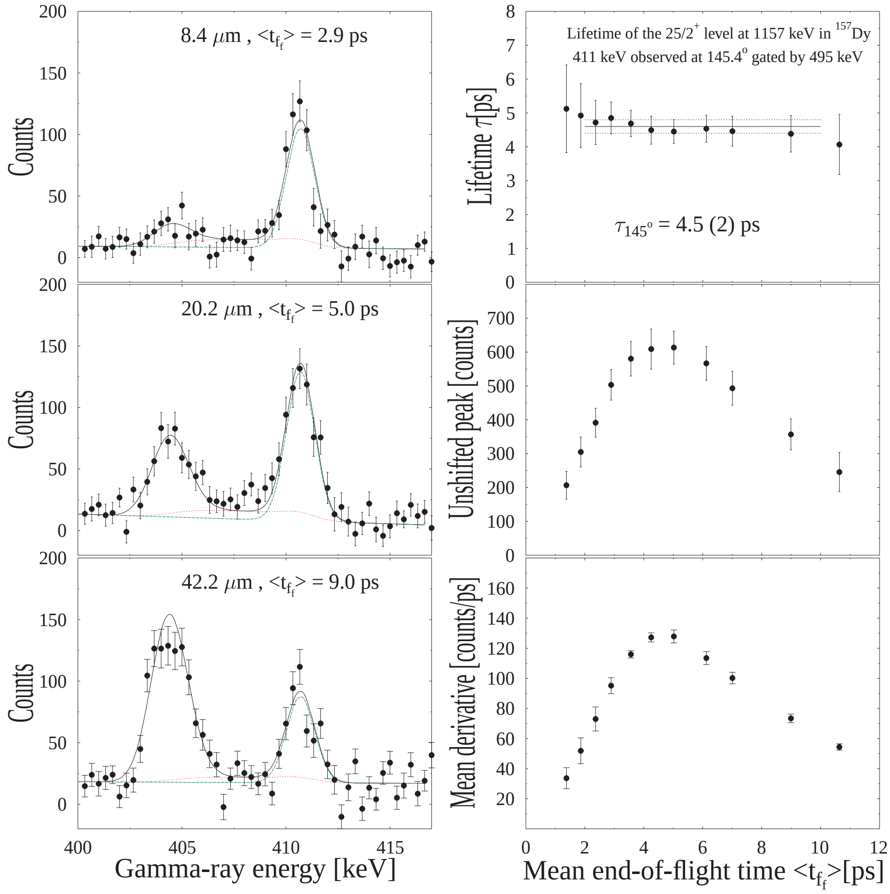

Figure 1. (Color online) Example of lifetime determination for the $25/2^+$ level in the yrast band of ^{157}Dy using the gated spectra measured with the detectors at 145°. The gate is set on the shifted component of the directly feeding 495 keV transition. The left part of the figure presents fits of the line shape of the 411 keV γ-ray transtion at different distances. The solid black line is the full fit. In addition, the fractions of the line shape related to the unshifted peak (dashed green line) and DSA effects (dotted red line) are shown. The right part of the figure illustrates the lifetime determiantion according to an equation given in [13]. On top, the τ-curve derived is displayed together with a fit with a horizontal line within the region of sensitivity.

4. Results and discussion

In the present work, 9 lifetimes were determined in the yrast band of ^{157}Dy, 3 of them for the first time. To describe the yrast band B(E2)'s in the present work, we used the rigid rotor model [19]. The comparison between our preliminary results (from RDDS and DSAM experiments) and the prediction of the rigid rotor model are shown in Fig. 2. The dependence of the transition strengths in the yrast band deduced from our analysis on the spin of the initial level is displayed. Up to spin $I^{\pi}=53/2^+$, the data are consistent with the predictions of the rigid-rotor model as shown by the comparison with two calculations. The latter were performed using Eq. 1 assuming $Q_0=6.51$ eb and two different values of the projection $K=\Omega$ of the angular momentum on the

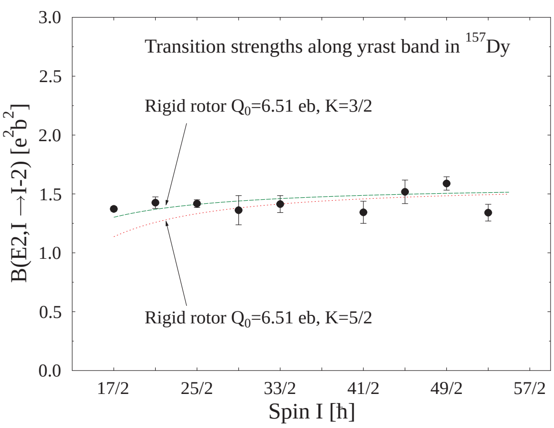

Figure 2. Reduced B(E2,I → I-2) transition strengths in the yrast band. The results of the RDDS measurements as well as results from DSAM data analysis are presented together with calculations within the rigid-rotor model with the indicated parameters

symmetry axis.

$$B(E2, I \rightarrow I-2) = \frac{5}{16\pi} e^2 Q_0^2 < IK20|I-2K >^2 \qquad (1)$$

Looking at the evolution of the β deformation in Dy isotopes we can see that it is smoothly rising from $\beta \approx 0.28$ in ^{155}Dy to $\beta \approx 0.30$ in ^{157}Dy as getting closer to midshell. In the framework of the rigid-rotor model the transition quadrupole moments within a band are equal to the intrinsic quadrupole moment Q_0 which is related [20] to the deformation β via Eq. 2. Due to the bigger value for β deformation the value for Q_0 is also rising from ≈ 5.8 eb in ^{155}Dy to ≈ 6.5 eb in ^{157}Dy.

$$Q_0 = \frac{3}{\sqrt{5\pi}} Z R_0^2 \beta (1 + 0.16\beta). \qquad (2)$$

The structure of the yrast band is dominated by the $3/2^+[651]$ quasineutron orbital, but with increasing spin, other low-Ω orbitals from $i_{13/2}$ parentage have an appreciable contribution in the wave functions. Both calculations (with K=3/2 and K=5/2) describe reasonably the data.

5. Summary and conclusions

In the present work, RDDS and DSAM lifetime measurements were carried out. For the data analysis, dedicated versions of the Differential decay curve method were employed. The data on the deduced transition strengths were compared to the results of rigid rotor model calculations. Pointing on this result we can say that there is no indication found for a reduction of the collectivity of the E2 transitions in the yrast band with increasing spin in the investigated spin range.

6. Acknowledgments

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