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Check for chirality in real nuclei

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Abstract. Exited states in ^{134}Pr were populated in the fusion-evaporation reaction ^{119}Sn(^{19}F, 4n)^{134}Pr. Recoil distance Doppler-shift and Doppler-shift attenuation measurements using the Euroball spectrometer, in conjunction with the inner BGO ball and the Cologne plunger were performed at beam energies of 87 MeV and 83 MeV, respectively. The measured $B(E2)$ values within the two chiral candidates bands are not identical while the corresponding $B(M1)$ values have a similar behaviour within the experimental uncertainties.

PACS. 21.10.Tg Lifetimes – 23.20.-g Electromagnetic transitions – 27.60.+j $90 \leq A \leq 149$ – 11.30.Rd Chiral symmetries

1 Introduction

Chirality is an interesting phenomenon which appears in chemistry, biology and particle physics. In ref. [1], it is pointed out that the rotation of triaxial nuclei may result in chiral doublet bands. Suggested candidates that exhibit chiral behaviour are nuclei in which the angular momenta of the valence proton, the valence neutron, and the core rotation are mutually perpendicular. This case can be realized in the mass $A \sim 130$ region where the proton Fermi surface is positioned low, and the neutron surface high in the high-j $h_{11/2}$ subshell. The most notable consequence of chirality is demonstrated as degenerate doublet $\Delta I = 1$ bands of the same parity. In the case of $\gamma = 30°$ and pure particle-hole configuration, the absolute $B(E2)$ and $B(M1)$ strengths of transitions depopulating the respective levels in these bands should be identical. The first pair of nearly degenerate bands based on the $\pi h_{11/2}$ $\nu h_{11/2}$ configuration was reported for ^{134}Pr in ref. [2]. The splitting between levels of the same spin and parity is decreasing with increasing spin and the bands cross above $I > 15\,\hbar$. This pair of bands has been interpreted as one of the best examples of chiral rotation [3]. They have been described within the framework of the particle-core coupling model [4] and the tilted-axis cranking model [1,5]. Recently, chiral candidate bands has been reported also in the mass region $A \sim 100$, *e.g.* in ^{104}Rh and ^{105}Rh [6,7,8].

It turns out that a classification based only on the excitation energies and branching ratios is not sufficient for a definite assignment. Critical experimental observables for the understanding of nuclear structure and for checking the reliability of the theoretical models are the electromagnetic transition probabilities. The goal of the present work is to investigate the nucleus ^{134}Pr, which is expected to be one of the very promising candidates to express chiral symmetry.

2 Experimental details and data analysis

Excited states in ^{134}Pr were populated using the reaction ^{119}Sn(^{19}F, 4n)^{134}Pr. For the Recoil distance Doppler-shift (RDDS) measurement, the beam, with an energy of 87 MeV, was delivered by the Vivitron accelerator of the IReS in Strasbourg. The target consisted of 0.5 mg/cm^2 Sn (enriched to 89.8% in ^{119}Sn) evaporated on a 1.8 mg/cm^2 ^{181}Ta backing. The recoils, leaving the target with a velocity of 0.98(2)% of the velocity of light, c, were stopped in a 6.0 mg/cm^2 gold foil.

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The γ-rays were detected using the EUROBALL IV spectrometer. Events were collected when at least three γ-rays in the Ge cluster or clover segments and three segments of the inner ball fired in coincidence. Data were taken at 20 target-to-stopper distances ranging from electrical contact to 2500 μm.

For the Doppler-shift attenuation measurement (DSAM), a beam of ^{19}F with an energy of 83 MeV provided by the Vivitron tandem was used. The target consisted of 0.7 mg/cm^2 Sn (enriched to 89.8% in ^{119}Sn) evaporated on a 9.5 mg/cm^2 ^{181}Ta backing used to stop the recoils.

The cluster and clover detectors of EUROBALL were grouped into 10 rings corresponding to approximately the same polar angle with respect to the beam axis. Some of the investigated transitions have low energies, and since v/c is 0.98(2)%, the resulting Doppler-shift is relatively small. In the analysis, only detectors with good resolution were selected in order to obtain better line-shapes. The good statistics for the low lying states of ^{134}Pr allowed to construct γ-γ coincidence matrices in which the angular information is conserved on both axes. For the higher lying states of ^{134}Pr, because of the weaker statistics, only matrices were constructed where one of the axes was associated with a specific detection angle while on the other axis every detector (ring) firing in coincidence was allowed.

For the analysis of the RDDS data, the standard version of the Differential decay-curve (DDCM) [9] method has been employed, with gates set on both shifted (S) and unshifted (U) peaks of a transition depopulating levels below the level of interest. A lifetime value is calculated at each distance and the final result for τ is determined as an average of such values within the sensitivity region of the data. More details about the DDCM applied to RDDS measurements can be found in refs. [9,10].

For the analysis of the DSAM data, we performed a Monte Carlo (MC) simulation of the slowing-down histories of the recoils using a modified [11,12] version of the program DESASTOP [13]. Complementary details on our procedure for Monte Carlo simulation as well as on the determination of stopping powers could be found in ref. [14]. The analysis of the line-shapes was carried out according to the DDCM procedure for treating DSAM data [10,11].

3 Results and discussion

The lifetimes of the levels with $I^\pi = 10^+$ to 18^+ in Band 1 and with $I^\pi = 12^+$ to 17^+ in Band 2 have been derived. Mixing ratios and relative intensities for the calculation of the $B(M1)$ and $B(E2)$ values were taken from ref. [2]. Within the experimental uncertainties, the $B(M1)$ values in both partner bands behave similarly, varying in an interval indicating relatively strong transition strengths. They smoothly decrease from about 1.8 μ_N^2 at the 10_1^+ level approaching 0.2 μ_N^2 for the 16_1^+ level and then again increase to about 0.4 μ_N^2 for the 18_1^+ level. The $B(M1)$ values for the corresponding levels of the second band are slightly higher then these in the first band, showing the same behaviour. In contrast, the intraband $B(E2)$ strengths within the two bands differ. In the investigated spin range, for Band 1 they initially decrease from about 0.3 e^{2}b^2 for the 11_1^+ level to 0.1 e^{2}b^2 for the 14_1^+ level. In the spin region 14_1^+ to 17_1^+, the $B(E2)$ values are almost constant and an increase is observed at the 18_1^+ level. The $B(E2)$ values for the 15^+ levels in both bands are similar. For Band 2 we observe a decrease of the $B(E2)$ values for levels with spins below and above 15_2^+. However, above the 16^+ level, the $B(E2)$ strengths in Band 1 are increasing. It is interesting to note that this effect occurs when Band 2 becomes yrast instead of Band 1, *i.e.* after the region where the two bands cross each other. We mention that the $B(M1)/B(E2)$ ratios reported in the ref. [2] also behave differently in the two bands. Those in Band 2 are higher compared to the corresponding values in Band 1.

Currently, there are no reasonable theoretical predictions in the literature which could reproduce the measured transition probabilities.

4 Conclusions

Fifteen lifetimes of excited states belonging to the candidate bands for a chiral doublet in ^{134}Pr have been determined. The intraband $B(M1)$ values are similar within the experimental uncertainties in both bands, while the corresponding $B(E2)$ transition strengths considerably differ, indicating that they are not completely identical structures. A precise description of the data is obviously a challenge for the nuclear models and in particular, for those which aim at the description of chirality of nuclear rotation.

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