Investigation of chirality in the case of 102Rh

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Abstract. Excited states in $^{102}$Rh were populated in the fusion-evaporation reaction $^{94}$Zr($^{11}$B, 3n)$^{102}$Rh at a beam energy of 36 MeV using the INGA spectrometer at IUAC, New Delhi. The angular correlations and the electromagnetic character of some of the gamma-ray transitions observed were investigated in details. A new chiral candidate sister band was found. Lifetimes of exited states in $^{102}$Rh were measured using the Doppler-shift attenuation technique and the derived reduced transition probabilities are compared to the predictions of the Two Quasiparticles Plus Triaxial Rotor model.

1. Introduction

Chirality is a phenomenon which is often found in nature. Examples for the existence of chirality are present in chemistry, biology, high energy physics etc. An interesting question arose last decade in nuclear physics, does chirality exists in this field? A spontaneous breaking of the chiral symmetry can take place for configurations where the angular momenta of the valence protons, valence neutrons, and the core are mutually perpendicular [1]. The projections of the angular momentum vector on the three principal axes can form either a left- or a right- handed system and therefore the system expresses chirality. Since the chiral symmetry is dichotomic, its spontaneous breaking by the axial angular momentum vector leads to a pair of degenerate I = 1 rotational bands, called chiral doublet bands. Pairs of bands, presumably due to the breaking of the chiral symmetry in triaxial nuclei, have been recently found in the mass regions $A \sim 130$ [2, 3, 4, 5, 6, 7], $A \sim 105$ [8, 9, 10, 11, 12, 13] and $A \sim 195$ [14, 15, 16], and $A \sim 80$ [17]. There is also a significant interest from theoretical point of view to investigate the chiral phenomenon [18, 19, 20, 21, 22, 23]. However, only in few cases ($^{126}$Cs [24], $^{128}$Cs [6] and $^{198}$Tl [15]) the
systematic properties [25] of the chiral bands, which originate from the underlying symmetry, were confirmed including the transition from chiral vibrations to static chirality in $^{135}$Nd [7]. In many cases the energy degeneracy of the chiral candidate bands was almost observed but the transition probabilities are different. This is clearly seen in the case of $^{134}$Pr [25, 26, 27]. According to the work [21] and [28], the nucleus of $^{102}$Rh is candidate to express multiple chirality. The main goal of the present work was to check for the existence of chirality in the mass region $A \sim 100$. In previous works [8, 11, 12], an island of chiral candidates has been proposed around $^{104}$Rh. Next to the identification of the twin bands, some lifetimes have been reported for the yrast band of $^{104}$Rh [12].

2. Experiment

Excited states in $^{102}$Rh were populated using the reaction $^{94}$Zr($^{11}$B,3n)$^{102}$Rh at a beam energy of 36 MeV. The beam was delivered by the 15-UD Pelletron accelerator at the Inter University Accelerator Center (IUAC) in New Delhi. The target consisted of 0.9 mg/cm$^2$ $^{94}$Zr, enriched to 96.5%, evaporated onto a 8 mg/cm$^2$ gold backing. The recoils were leaving the target with a mean velocity $v$ of about 0.9% of the velocity of light, $c$. The de-exciting gamma-rays were registered by the Indian National Gamma Array (INGA), whose 15 Clover detectors are accommodated in a 4$\pi$ geometry [29]. For the purposes of the Doppler-Shift Attenuation Method (DSAM) analysis the detectors of INGA which lie at approximately the same polar angle with respect to the beam axis were grouped in five rings. Doppler broadened line shapes were observed for transitions depopulating higher spin levels. The rings where appreciable Doppler-shifts are observed are these at angles of 32, 57, 123 and 148 degrees. Gain matching and efficiency calibration of the Ge detectors were performed using $^{152}$Eu and $^{133}$Ba radioactive sources before sorting the data in matrices and cubes.

Figure 1. Partial level scheme of $^{102}$Rh. Two negative-parity bands, candidates for chiral partner bands, are indicated as band 1 and band 2.
Table 1. Derived lifetimes in Band 1 and Band 2 of $^{102}$Rh.

| Band 1 | $E_{ex}$ [keV] | State [I$^\pi$] | $\tau$ [fs] |
|--------|----------------|-----------------|------------|
|        | 1576           | (11)$_1^-$      | 458(44)    |
|        | 2038           | (12)$_1^-$      | 227(58)    |
|        | 2477           | (13)$_1^-$      | 320(71)    |
|        | 2965           | (14)$_1^-$      | 170(25)    |
|        | 3494           | (15)$_1^-$      | 117(39)    |
|        | 4022           | (16)$_1^-$      | 68(14)     |

| Band 2 | $E_{ex}$ [keV] | State [I$^\pi$] | $\tau$ [fs] |
|--------|----------------|-----------------|------------|
|        | 1731           | (10)$_2^-$      | 163(52)    |
|        | 2183           | (11)$_2^-$      | 156(60)    |
|        | 2542           | (12)$_2^-$      |            |

3. Data analysis and results

The detectors of INGA were grouped into rings positioned with respect to the beam axis. This is needed for DSAM analysis. The rings with appreciable Doppler-shifts are these at angles of 32, 57, 123 and 148 degrees. For the investigation of the level scheme and electromagnetic properties of the transitions in $^{102}$Rh we have performed four different types of data analyses. On Fig. 1 is shown the level scheme of $^{102}$Rh. The ordering of the transitions in the level scheme was determined according to $\gamma$-ray relative intensities, $\gamma$$\gamma$ coincidence relationships, and $\gamma$-ray energy sums. The multipolarity and the character of the transitions were deduced from the investigation of linear polarization and angular correlations measurements. For this purpose the clover detectors from the ring at 90° were used as a Compton polarimeter [30]. The lifetimes of excited states in $^{102}$Rh were derived using the Doppler-shift attenuation methods. The analysis was carried out within the framework of the Differential decay method (DDCM)[31] according to the procedure outlined in [32] where details about the Monte-Carlo simulation of the slowing down process, determination of stopping powers and fitting of line shapes can be found.

For each level, lifetimes were derived independently at the four rings with appreciable Doppler shifts. The final values of the lifetimes are presented in Table 1. Thus, we have succeeded to extend the known level scheme [33] by a new $\Delta I = 1$ band with a negative parity and to determine 8 new lifetimes. The reduced transition probabilities $B(\sigma\lambda)$ deduced from lifetime data are presented in [34].

To study the bands based on the $\pi g_{9/2} \otimes \nu h_{11/2}$ configuration, we have performed two quasiparticles + triaxial rotor (TQPTR) calculations in the framework of the model presented in Ref. [36]. The Hamiltonian of this model includes the rotational energy of the core, the quasiparticle energies of the odd proton ($\pi$) and neutron ($\nu$), and a residual proton-neutron interaction $V_{\pi\nu}$. The core is treated as a rigid body with a fixed overall quadrupole deformation $\epsilon$ and a triaxiality parameter $\gamma$. On Fig. 2 is shown the comparison between the experimental and calculated B(M1) transition strengths which leads to the conclusion that this model reproduce roughly the data in Band 1 and is consistent with the transition strenght in Band 2. The theoretical $B(E2)$ reproduce quite well the absolute values and the increasing trend of the experimental data after spin $I = 14$ $h$. The behaviour of the $B(E2)$ transition strengths in $^{102}$Rh is very similar to what has been observed in $^{134}$Pr [26]. The TQPTR calculations reveal that the optimum value of the triaxiality parameter $\gamma = 20^\circ$ differs from the value of $30^\circ$ characterizing chirality.

The present results come to supercede the preliminary level-scheme published in [35]. The absence of an appreciable staggering of the data in Band 1 indicates that the expectations for
Figure 2. Experimentally derived and theoretically calculated $B(E2)$ and $B(M1)$ transition strengths in $^{102}$Rh. In the upper panels are presented experimental $B(E2)$ and $B(M1)$ values for transitions in Band 1 and Band 2. In the second row, the results of TQPTR calculations are displayed.

the observation of a state chirality in $^{102}$Rh are not realized [34].

4. Conclusions
In order to investigate the level-scheme and to determine lifetimes of the excited states in the chiral candidate nucleus of $^{102}$Rh we have performed an experiment at the Inter University Accelerator Center in New Delhi using the INGA spectrometer. Lifetimes in $^{102}$Rh were measured by means of the Doppler-shift attenuation method. We have succeeded to extend the known level scheme [33] by a new $\Delta I = 1$ band with a negative parity and to determine 8 new lifetimes in the sub-picosecond region. For the interpretation of our results we applied two quasiparticles plus triaxial rotor model. We have succeeded to extend the level-scheme with a new $\Delta I = 1$ band with a negative parity. Our lifetime measurements and the theoretical analysis do not support static chirality in $^{102}$Rh. This means that the chirality in $^{102}$Rh, if it exists, has mainly a dynamical character.
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