Exploring the Origin of Nearly Degenerate Doublet Bands in ^{106}Ag

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To provide a stringent test of the chiral interpretation for a nearly degenerate doublet band member states in ^{106}Ag we propose to measure absolute electromagnetic transition probabilities for the bands in ^{106}Ag to high spins using the Doppler-shift attenuation method. The levels of interest will be populated using the ^{14}N(^{96}Zr,4n)^{106}Ag reaction at a beam energy of 70MeV.

I. SCIENTIFIC MOTIVATION

Chirality is a recently recognized form of spontaneous symmetry breaking in nuclear rotations [1, 2]. This phenomenon is related to time reversal and can occur if the valence protons, valence neutrons and the core couple their angular momenta in a mutually perpendicular way. Such geometry can be realized in odd-odd nuclei at intermediate spins when the Fermi level is located in the lower high-j subshell for protons (neutrons) and in the upper subshell for neutrons (protons) and the core is sufficiently triaxially polarized. Then the angular momenta of the valence particles and the triaxial core form either a left- or a right-handed system [2]. Consequently, the total angular momentum $\vec{I}$ is tilted with respect to the planes defined by the principal axes of the nucleus. This leads to doubly degenerate eigen states. The spontaneous formation of chirality in the body-fixed system results in $\Delta I = 1$ degenerate doublet bands in the laboratory reference system.

Thus, a pair of bands can be experimentally identified as chiral partners, provided that they exhibit nearly similar band structures, moments of inertia (MOI), and, more importantly, the transition probabilities [3]. Such situations have been best realized in ^{128}Cs [4] and ^{135}Nd

[5] for the A ~ 130 region. In recent years, a number of doublet bands have also been reported in the A ~ 100 [6–10] region, but their band structures and MOI have been found to be different. In addition, the transition rates have not been measured. Thus, the origin of these bands of the A ~ 100 region could not be established.

In two papers published few months ago [11,12] were reported measurements of transition rates in the doublet bands of ^{106}Ag. The results of these measurements are not in agreement.

In the first paper [11] a thorough spectroscopic and theoretical investigation of the negative-parity bands in ^{106}Ag has been carried out. The bands have been revised and extended, and their lifetimes were measured using the Doppler-shift attenuation method, representing the first high-quality lifetime measurement of the proposed chiral bands in the mass A ≈ 100 region. The analysis of alignments and comparison of theoretical and experimental results allow a new understanding of the conundrum represented by the crossing bands 1 and 2 (see Fig.1). They find that while band 1 corresponds to a $\pi g_{9/2}^{-1} \otimes \nu h_{11/2}$ two-quasiparticle configuration, band 2 neither has a two-quasiparticle configuration nor results from the alignment of a pair of $h_{11/2}$ neutrons [13]. It is conclusive that bands 1 and 2 do not form a pair of chiral-partner bands as proposed by Joshi et al. [7].

The crossing between bands 1 and 2 is caused by configurations of different alignment. Although their electromagnetic properties are not fully understood, bands 2 and 3 are in reasonable agreement with the properties expected for $\pi g_{9/2}^{-1} \otimes \nu\{d_{5/2}; g_{7/2}\}^2 \nu h_{11/2}$ four-quasiparticle configurations.

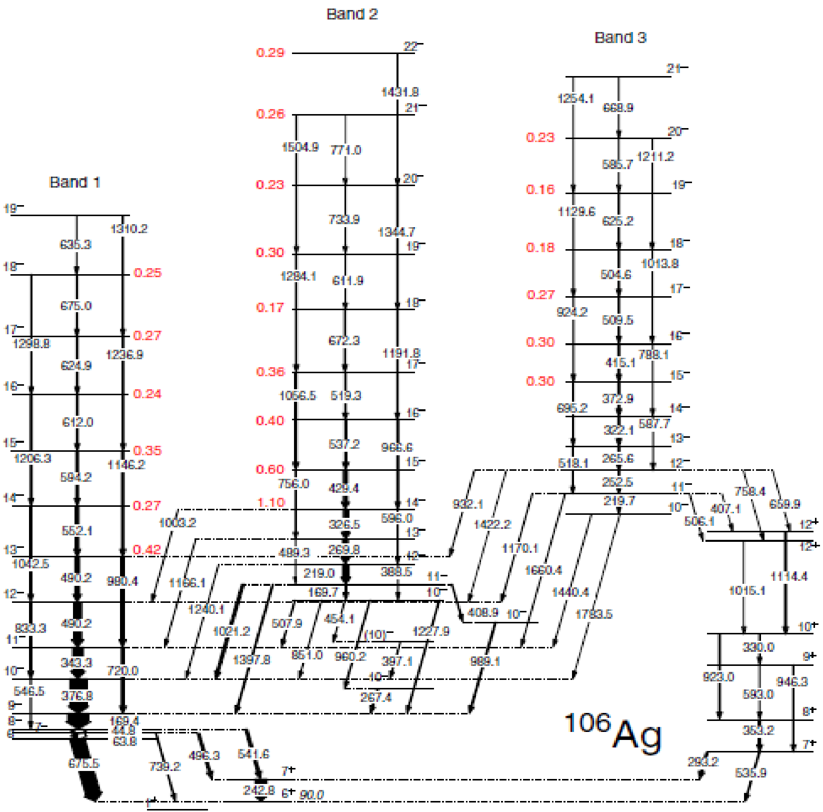

Fig. 1 Partial level scheme of ^{106}Ag [11].

In the second paper [12], the deduced transition rates within the experimental uncertainties (see Fig.2) for the two bands are essentially the same, except at I = 15ħ, which probably originates due to the band crossing around this spin. The observation that the B(E2; I → I–2) are similar does not support the two different quasiparticle pictures of Ref. [14], since in that case, the rates in the partner band are expected to be 2 times stronger than that of the main band. However, the explanation based on two different shapes cannot be ruled out, since the measured B(E2; I → I–2) values for the main and partner bands can be reproduced by different sets of (β, γ) values.

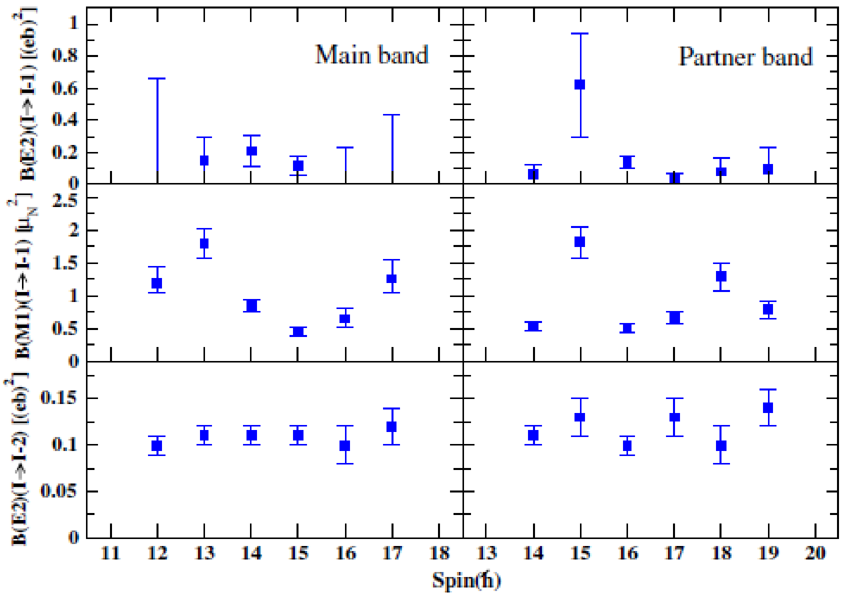

Fig. 2 The deduced B(E2; I → I – 1),B(M1; I → I – 1), and B(E2; I → I – 2) rates for the doublet bands of ^{106}Ag [12].

Similar precise level lifetime measurements in nearly degenerate doublet bands have only been performed in the A ~ 130 region for ^{128}Cs [4], ^{135,136}Nd [5,15], and ^{134}Pr [16]. The MOI and transition rates were found to be very similar in ^{128}Cs and ^{135}Nd, which established that the doublet bands are chiral partners. On the other hand, the doublet bands of ^{134}Pr and ^{136}Nd exhibit the band crossing similar to that observed in ^{106}Ag. In both cases, the transition rates were found to be different and were interpreted within the frameworks of the interacting boson-fermion-fermion model and the tilted axis cranking model complemented by the random phase approximation. These calculations indicated that the dissimilar transition rates in the doublet bands of ^{136}Nd and ^{134}Pr may originate due to chiral vibration [15] and chiral fluctuation [16], respectively. However, in the present work, similar transition rates have been observed in the doublet bands of ^{106}Ag. This novel feature of different MOI but similar transition rates may contain a new physical insight into the origin of the doublet bands which are systematically observed in the transitional region of the nuclear chart.

Based on the results from these two investigations (measured lifetimes from both experiments are shown on Fig.1 and Table 1), it is evident that the nature of a nearly degenerate doublet band member states in ^{106}Ag is not clear yet. That's why we propose to make a third measurement with the same reaction to verify earlier data and make the situation clearer.

Spin $I(\hbar)$	Lifetime (ps)	Mixing ratio (δ)	Branching ratio $\frac{I_\gamma(\Delta I=1)}{I_\gamma(\text{total})}$
		Main band	
12^-	0.32(2)		0.84(7)
13^-	0.20(2)	0.12(5)	0.76(6)
14^-	0.23(2)	0.23(5)	0.61(5)
15^-	0.22(2)	0.25(6)	0.40(4)
16^-	0.17(1)		0.47(7)
17^-	0.10(1)		0.57(7)
		Partner band	
14^-	1.77(10)	0.09(4)	0.58(5)
15^-	0.31(3)	0.21(5)	0.87(7)
16^-	0.40(3)	0.24(3)	0.57(6)
17^-	0.27(2)	0.11(4)	0.45(5)
18^-	0.10(1)	0.14(7)	0.70(9)
19^-	0.11(1)	0.18(6)	0.36(5)

TABLE I. The measured lifetimes for the levels of the doublet bands, the corresponding mixing ratios, and the branching ratios of ^{106}Ag [12].

II. EXPERIMENTAL DETAILS

In order to resolve this issue and to get an insight into the origin of partner bands in the A ~ 100 region, the high-spin states of ^{106}Ag will be populated through the ^{96}Zr (^{14}N, 4n) reaction using a 70MeV ^{14}N beam delivered by the Tandem van de Graaff accelerator in Bucharest. A 17 mg/cm^2 thick self-supporting metallic ^{96}Zr foil will be used as target, which facilitates the measurement of the subpicosecond lifetimes for the high-spin levels of the main and the partner bands by using the Doppler-shift attenuation method. The γ rays emitted from the ^{106}Ag nuclei will be detected by the HpGe spectrometer array ROSPHERE, based at the IFIN-HH laboratory, Bucharest [17].

Summary of the experimental details:

Reaction: ^{14}N(^{96}Zr, 4n)^{106}Ag
Beam: 70 MeV, 2-3 pnA
Targets: self-supporting metallic ^{96}Zr foil of 17 mg/cm^2
Maximum initial recoil velocity: v/c ~ 1.3%, in the target
Bucharest γ-Spectrometer
Requested beam time: 21 shifts (7 days)

III. REFERENCES

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