Study of the 107Ag Magnetic Rotation Band

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Abstract

In this work, high-spin states of the 107Ag nucleus were populated via the heavy-ion fusion-evaporation reaction 100Mo(11B,4n)107Ag using a 46 MeV 11B beam. The level scheme of 107Ag has been extended, with six new energy levels and eleven new transitions identified within positive-parity band 2 and its linking transitions, and the spin-parity of the band-2 bandhead was confirmed as 27/2+. Through analyses of spin-dependent properties including excitation energies, alignments, signature splitting, and B(M1)/B(E2) ratios, as well as comparative analysis with the band structure of neighboring 111In, band 2 in 107Ag is proposed to be a magnetic rotational band with configuration πg9/2vh\$$^{\{2\}1/2(d5/2/97/2)}${2}\$.

Full Text

Investigation of Magnetic Rotational Band in 107Ag

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Abstract

High-spin states of the 107Ag nucleus were populated via the heavy-ion fusion-evaporation reaction 100Mo(11B, 4n)107Ag using a 46 MeV 11B beam. The level scheme of 107Ag has been extended, revealing six new levels and eleven new

γ transitions within and connecting the positive-parity band 2, confirming the bandhead spin-parity as $27/2^{+}$. Through analysis of spin-dependent properties including excitation energies, alignments, signature splitting, and B(M1)/B(E2) ratios, together with comparative studies of the band structure in neighboring 111In, band 2 in 107Ag is proposed to be a magnetic rotational band with the configuration πg9/2 h11/2^2(d5/2/g7/2)^2.

Keywords: Heavy-ion fusion evaporation reaction; High-spin states; Magnetic rotation

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1. Introduction

Magnetic rotation in atomic nuclei was first observed in the early 1990s in near-spherical lead isotopes [1–3]. Subsequently, numerous examples of magnetic rotation have been discovered in various mass regions including A 200, 140, 100, 80, and 60. Unlike conventional rotational bands in deformed nuclei, magnetic rotation arises from the alignment of valence nucleons outside the nuclear core along a tilted axis—hence the term "tilted-axis rotation." The competition between spatial orientations of valence protons and neutrons substantially enhances the nuclear magnetic moment, leading to strong cascades of magnetic dipole (M1) γ transitions. This excitation mode is therefore termed magnetic rotation (MR).

Magnetic rotation occurs in near-spherical nuclei when their symmetry is broken by a few excited high-j particles and holes. Nuclei exhibiting magnetic rotation show level patterns similar to collective rotation (electric rotation) about an axis perpendicular to the symmetry axis, approximately following the relation E(I) E0 / I(I + 1). However, their electromagnetic transition properties feature strong M1 transition probabilities with B(M1)/B(E2) ratios that decrease slowly with increasing angular momentum [5]. Several theoretical models have been successfully developed to describe magnetic rotation, including the Tilted Axis Cranking (TAC) model [6], Tilted Axis Cranking based on Covariant Density Functional Theory (TAC-CDFT) [7–9], and the Triaxial Projected Shell Model (TPSM) [10].

The nucleus 107Ag has Z = 47 protons and N = 60 neutrons, situated in the A 110 mass region. Nuclei in this region have proton numbers near the closed shell at Z = 50 and thus exhibit small deformation. Valence protons readily occupy the g9/2 orbital, while valence neutrons favor the d5/2, g7/2, and h11/2 orbitals—configurations conducive to magnetic rotation. Magnetic rotational bands have been identified in several Ag isotopes including 103Ag [11–13], 104Ag [14], 105Ag [13, 15], 106Ag [13, 16], and 109Ag [17], suggesting that 107Ag may also harbor magnetic rotational bands warranting further investigation.

Early studies of 107Ag date back to 1979, when Schuh et al. populated lower-spin states via the 104Ru(6Li, 3n)107Ag and 104Ru(7Li, 4n)107Ag reactions

[18]. In the same year, Popli et al. used the 96Zr(14N, 3n)107Ag reaction to populate lower-spin levels and analyzed them using the rotor model [19]. Later, Jerrestam et al. employed the 94Zr(17O, p3n)107Ag reaction to establish a relatively complete level scheme for high-spin states, though band 2 was only weakly connected to the yrast band (band 1) via a single 990 keV γ transition, with four disconnected levels below band 2 showing no linking transitions to band 1 [20]. Subsequent work using the 100Mo(11B, 4n)107Ag reaction focused on negative-parity side bands, proposing configuration assignments and discussing signature splitting [21], while further studies with the same reaction refined the negative-parity bands and discussed possible chiral doublet bands [22]. Lifetime measurements were performed to investigate the magnetic rotation characteristics of band 1 and a negative-parity band, but the positive-parity band 2 was not addressed [26].

This work presents experimental studies of the positive-parity high-spin states in 107Ag. By establishing inter-band linking transitions and extending the level scheme, we investigate the magnetic rotation characteristics of the positive-parity band 2 through comparisons of level energies, alignments, signature splitting, kinematic moments of inertia, and B(M1)/B(E2) ratios as functions of spin.

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2. Experiment and Results

The experiment was conducted at the HI-13 Tandem Accelerator Nuclear Physics Laboratory of the China Institute of Atomic Energy. High-spin states in 107Ag were populated via the heavy-ion fusion-evaporation reaction 100Mo(11B, 4n)107Ag using a 46 MeV 11B beam. The target consisted of highly enriched 100Mo with a thickness of 0.97 mg/cm^2, backed by natural Yb with a thickness of 8.8 mg/cm^2.

The γ-ray detection array comprised 12 HPGe-BGO anti-Compton spectrometers and two planar HPGe detectors. Specifically, five coaxial HPGe detectors were placed at 90° relative to the beam direction, two coaxial detectors each at 42° and 140°, three HPGe detectors at 150°, and the two planar HPGe detectors at 127° and 34° relative to the beam axis. Approximately 6.5×10^7 twofold and higher-fold γ-γ coincidence events were recorded. All HPGe detectors were calibrated for energy and efficiency using standard 60Co, 133Ba, and 152Eu sources.

Offline analysis involved generating both symmetrized Eγ-Eγ two-dimensional matrices and asymmetric directional correlation (DCO) matrices for level scheme construction and DCO ratio extraction. Figure 1 [Figure 1: see original paper] shows typical DCO ratios for γ transitions in 107Ag extracted in this experiment, where gates on ΔI = 2 transitions at 866 keV, 1063 keV, and 1095 keV yield DCO ratios for both ΔI = 1 and ΔI = 2 γ transitions.

Under the present experimental conditions, when gating on $\Delta I = 2$ quadrupole transitions, the RDCO values for $\Delta I = 2$ quadrupole transitions are near 1, while those for $\Delta I = 1$ dipole transitions are approximately 0.8. Data analysis was performed using the PC-Linux-based RADWARE and GASPWARE software packages.

Based on γ–γ coincidence relationships and energy-intensity balance principles, the level scheme of 107Ag was extended as shown in Figure 2 [Figure 2: see original paper]. Spin-parity assignments for each level were made based on RDCO values and previously reported assignments [20, 21]. Compared with earlier works [20–22], the level scheme has been significantly expanded, with six new levels and eleven new γ transitions identified within and connecting positive-parity band 2. The positions of three previously known γ transitions have been adjusted. These γ rays have energies of 258.7 keV, 549.2 keV, 287.6 keV, 578.4 keV, 998.1 keV, 1220.3 keV, 937.3 keV, 966.8 keV, 536.9 keV, 674.9 keV, 1137.7 keV, 1269.2 keV, 1014.6 keV, and 982.1 keV, among which the 287.6 keV, 937.3 keV, and 1014.6 keV transitions were previously observed [20]. Band 2 now feeds into band 1 through these newly discovered or repositioned γ transitions, as illustrated in Figure 2 [Figure 2: see original paper].

Figure 3 [Figure 3: see original paper] presents gate spectra for γ rays at 865.6 keV, 1095.0 keV, 318.1 keV, and 290.1 keV. The newly discovered γ transitions are clearly visible in these spectra, and all previously reported γ rays are observed. In the spectra, newly found γ rays are marked in red, repositioned ones in green, while certain γ rays originate from negative-parity bands in 107Ag or from contaminant peaks of 106Ag.

An additional dataset from a separate 11B + 100Mo experiment [22, 23] was analyzed for detailed comparison. While confirming the new γ rays, we attempted to extract DCO ratios for several intense new transitions: 258.7 keV, 287.6 keV, 1269.2 keV, 1014.6 keV, 674.9 keV, and 982.1 keV, obtaining values of 0.78$\pm 0.26, 1.09\pm 0.39, 1.96\pm 0.81, 0.92\pm 0.32, 1.77\pm 0.67, and 1.11\pm 0.57, respectively. Although statistical uncert$ $parities from literature [20, 21], allow tentative assignments of 27/2^{\{+\}, 27/2}\{+\}, 19/2^{\{+\}, 23/2}\{+\}, and 19/2$^{+} for the new levels at 4709 keV, 4680 keV, 3068 keV, 3744 keV, and 3068 keV, respectively.

Based on these assignments, the de-excitation from the 4709 keV level to the 3036 keV level involves a spin change of ΔI 4ħ, suggesting that the 536.9 keV and 1137.7 keV γ transitions are both $\Delta I = 2$ E2 transitions. Consequently, the level at 4173 keV can be tentatively assigned as $(23/2^{+})$.

From the experimental data, the two levels at 4709 keV and 4680 keV both have spin-parity $27/2^{+}$. The 258.7 keV and 549.2 keV γ transitions feeding the 4709 keV level, and the 287.6 keV and 578.4 keV γ transitions feeding the 4680 keV level, all show coincidence relationships with band 2 intra-band transitions and follow rotational band systematics. The relative intensities of the 258.7 keV and 287.6 keV transitions are comparable, indicating no significant preferential population of either the 4709 keV or 4680 keV level. The 4680 keV $(27/2^{+})$

level de-excites directly to band 1 via the 998.1 keV and 1220.3 keV linking transitions. Although no direct de-excitation from the 4709 keV level to band 1 was observed, the newly identified levels at 3068 keV and 3744 keV have spin-parities and energies very similar to the 2892 keV and 3460 keV levels in band 1, possibly representing favored and unfavored configurations formed by breaking a pair of h11/2 neutrons into different orbitals.

The 578.4 keV transition from the $31/2^+$ level at 5257 keV to the $27/2^+$ level at 4680 keV is observed in gates on the 318.1 keV and 369.7 keV γ transitions, as shown in Figure 4 [Figure 4: see original paper]. No evidence was found for possible 1027 keV and 1249 keV γ transitions de-exciting the $27/2^+$ bandhead to band 1, and gating on the 1027 keV ($15/2^+ \rightarrow 11/2^+$) transition did not reveal a 1027 keV peak.

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3. Discussion

Band 2 is a positive-parity band that exhibits multiple linking transitions to the yrast band (band 1) with configuration πg9/2 h11/2^2. Similar band structures have not been observed in 103Ag, 105Ag, or 109Ag. However, in neighboring odd-A nuclei 103Rh [24] and 105Rh [25], band structures linked to the πg9/2 h11/2^2 yrast band have been identified as candidate chiral doublet bands. This raises the possibility that band 2 might be the chiral partner of band 1.

To evaluate this hypothesis, we compare the energy levels, alignments, signature splitting, and kinematic moments of inertia of bands 1 and 2 as functions of spin, as shown in Figure 5 [Figure 5: see original paper]. The energy difference between band 1 and band 2 at the bandhead ($27/2^+$) is 0.7 MeV, decreasing to 0.024 MeV at $39/2^+$ and becoming -0.125 MeV at $41/2^+$, with the energy curves crossing between $39/2^+$ and $41/2^+$. Without observation of higher-spin de-exciting γ rays, the trend beyond this crossing cannot be determined. The signature splitting S(I) = [E(I) - E(I - 1)]/2I differs significantly between the bands: band 1 shows clear signature splitting, while band 2 exhibits smooth behavior with almost no splitting, indicating different responses to the Coriolis force. The alignments differ by 2–3$\hbar$, suggesting different configurations. The kinematic moments of inertia also differ substantially, implying different nuclear shapes.

Although bands 1 and 2 share the same parity and show near-degeneracy over a certain spin range, the signature splitting is not constant, and their alignments and kinematic moments of inertia differ considerably. Based on this analysis, bands 1 and 2 in 107Ag do not exhibit the characteristics of candidate chiral doublet bands and likely have different configurations.

Nuclei in magnetic rotation modes exhibit several key features: intra-band transitions consist of strong M1 magnetic dipole transitions with weak or unobserved electric quadrupole E2 transitions; B(M1) values are large (approximately 2-

10 ^{2}N), B(E2) values are small (approximately 0.1-1 e^{2}b^2), resulting in large B(M1)/B(E2) ratios (approximately 10-100 (^{2}N/e^{2}b^2)) that decrease slowly with increasing angular momentum; and J(2)/B(E2) values are an order of magnitude larger than those in normally deformed bands (10 ħ^{2}MeV^{-1}/e^{2}b^2).

For band 2 in 107Ag, the γ-transition intensities indicate strong M1 and weak E2 transitions. As shown in Figure 5b, band 2 exhibits smaller signature splitting than band 1. The experimental B(M1)/B(E2) ratios were extracted using the formula:

$$\frac{B(M1; I \to I-1)}{B(E2; I \to I-2)} = 0.697 \frac{[E_\gamma(I \to I-2)]^5}{[E_\gamma(I \to I-1)]^3} \frac{1}{\lambda} \frac{1}{1+\delta^2}$$

where 1+δ^2 1, λ is the branching ratio:

$$\lambda = \frac{T_\gamma(I \to I-2)}{T_\gamma(I \to I-1)} = \frac{I_\gamma(I \to I-2)}{I_\gamma(I \to I-1)}$$

Due to weak γ-ray intensities and contaminant peaks, the extracted B(M1)/B(E2) ratios have large uncertainties, but their values exceed 10 and show a gradual decreasing trend with increasing spin, as shown in Figure 7 [Figure 7: see original paper].

A lifetime measurement for the 35/2$^+$ level in band 2 yielded τ 0.28 ps, corresponding to B(E2) 0.2 e^{2}b^2 (similar to band 1) and B(M1) 3.5 ^{2}N. The dynamic moment of inertia J(2) for band 2 ranges between 15-28 ħ^{2}MeV^{-1}. Combining these data gives J(2)/B(E2) 100 ħ^{2}MeV^{-1}/e^{2}b^2, consistent with magnetic rotation characteristics. We therefore propose that band 2 in 107Ag is a magnetic rotational band with configuration πg9/2 h11/2^2(d5/2/g7/2)^2.

The similarity between bands 1 and 2 in 107Ag and the corresponding bands in neighboring odd-A nucleus 111In [27] is noteworthy. In 111In, one band has configuration πg9/2 h11/2^2, while another involves an additional broken pair of d5/2/g7/2 neutrons. Lifetime measurements suggest both are magnetic rotational bands. Figure 6 [Figure 6: see original paper] compares the spin versus rotational frequency trends for the two pairs of bands, showing similar behavior likely arising from analogous intrinsic configuration changes.

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4. Conclusion

In this work, high-spin states in 107Ag were populated via the 100Mo(11B, 4n)107Ag reaction, extending the level scheme and identifying six new levels and eleven new γ transitions in positive-parity band 2, confirming the bandhead spin-parity as 27/2$^+$. Analysis of excitation energies, alignments, signature splitting, and B(M1)/B(E2) ratios indicates that band 2 is not a chiral partner of band 1 but rather a magnetic rotational band with configuration πg9/2 h11/2^2(d5/2/g7/2)^2.

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Note: Figure translations are in progress. See original paper for figures.