Properties of the $\pi h_{9/2} \otimes \nu i_{13/2}$ band in odd-odd $^{188}$Au

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A new rotational band has been identified and assigned to $^{188}$Au for the first time using the $^{173}$Yb($^{19}$F,4$n$γ) reaction at the beam energies of 86 and 90 MeV. This band is proposed to be built on the $\pi h_{9/2} \otimes \nu i_{13/2}$ configuration by comparing the band properties with known bands in neighboring nuclei. The prolate-to-oblate shape transition through triaxial shape has been proposed to occur around $^{188}$Au for the $\pi h_{9/2} \otimes \nu i_{13/2}$ bands in odd-odd Au isotopes on the basis of total Routhian surface (TRS) calculations.

high-spin states, shape evolution, triaxial shape, signature inversion

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1 Introduction

There is a well-known region of shape coexistence in Pt-Au-Hg nuclei. The low-lying 0$^+$ state in the Hg isotopes is thought to have an oblate shape while the second 0$^+$ state decreases rapidly in excitation energy from $^{188}$Hg to $^{184}$Hg and has been described as having prolate shapes (see ref. [1] and references therein). In contrast to the Hg isotopes, the lowest 0$^+$ states in $^{178-186}$Pt are prolate with the excited states 0$^+$ being oblate [2,3]. In Au isotopes a shape competition is well known between the slightly deformed oblate shape in heavier isotopes and the moderately deformed prolate shape in lighter isotopes [4–9]. The proton Fermi level in Au nuclei lies between the $\pi h_{11/2}$ and $\pi h_{9/2}$ subshells. For nuclei with oblate shape the odd proton occupies a low-$\Omega \ h_{11/2}$ orbital, while for prolate shape it occupies a low-$\Omega \ h_{9/2}$ orbital. The $^{184-186}$Au ground states have been known with prolate deformation [4–7], whereas the $^{187,189}$Au ground states are associated with oblate configuration [8,9]. Therefore, the spectroscopic information of $^{188}$Au is of particular interest as it lies at the critical point of prolate-to-oblate shape transition where the change in collective structure should be most drastic. One expects that a variety of shapes depending on the quasiparticle configurations could be observed experimentally in $^{188}$Au.

Prior to this work, high-spin states in $^{188}$Au were investigated by Janzen et al. [7] via $^{173}$Yb($^{19}$F,4$n$γ) reaction. The high-spin level structure has been proposed to be associated with $\pi h_{11/2} \otimes \nu i_{13/2}$ and $\pi h_{11/2} \otimes \nu i_{13/2} j = (p_{3/2}, f_{5/2})$ oblate configurations [7]. Noting that the low-lying prolate state with $\pi h_{9/2} \otimes \nu i_{13/2}$ configuration [8,9] has been observed in $^{187}$Au and $^{189}$Au, one may expect the existence of rotational band with proton occupying the $h_{9/2}$ orbital in $^{188}$Au. In this study, we report the experimental results of high-spin structure in $^{188}$Au, and discuss the properties of the rotational band associated with the $\pi h_{9/2} \otimes \nu i_{13/2}$ configuration.

2 Experiments and results

The excited states of $^{188}$Au were populated via the 4$n$ evaporation channel following the fusion of a $^{19}$F beam with an
\( ^{173}\text{Yb} \) target. The \(^{19}\text{F} \) beam was provided by the tandem accelerator at the Japan Atomic Energy Agency (JAEA). The target was a 2.2 mg/cm\(^2\) thick isotopically-enriched \(^{173}\text{Yb} \) metallic foil with a 7.0 mg/cm\(^2\) Pb backing. A \( \gamma \)-ray detector array GEMINI [10] was used to measure the X-\( \gamma \) and \( \gamma-\gamma \) coincidence within a time interval of \( \pm 100 \) ns. The array consists of 18 large volume HPGe detectors with BGO anti-Compton shields; 6 detectors had an efficiency of 40\% each and the others had 70\% relative to \( 3'' \times 3'' \) NaI. The energy and efficiency calibrations were made using \(^{60}\text{Co} \), \(^{133}\text{Ba} \), and \(^{152}\text{Eu} \) standard sources. Typical energy resolutions were about 2.0–2.5 keV at full width at half maximum for the 1332.5-keV \( \gamma \) ray energy.

In order to identify the in-beam \( \gamma \) rays belonging to \(^{188}\text{Au} \), relative \( \gamma \)-ray yields were measured at beam energies of 86 and 90 MeV, respectively. At each beam energy, about \( 80 \times 10^6 \) \( \gamma-\gamma \) coincidence events were accumulated and sorted on-line into a symmetric \( E\gamma-E\gamma \) matrix of \( 4k \times 4k \) size. Along with the \(^{188}\text{Au} \) nucleus, the \(^{187,189}\text{Au} \) nuclei were also produced in \(^{173}\text{Yb}(^{19}\text{F},2\pi n) \) reaction. The level schemes of \(^{187}\text{Au} \) and \(^{189}\text{Au} \) had been well known from previous studies [8,9]. From careful analyses of the relative yields of known \( \gamma \) rays from \(^{187,188,189}\text{Au} \), we found that the relative intensity of the new 328.3- and 449.5-keV \( \gamma \) rays has a similar pattern with that of the known \( \gamma \) rays from \(^{188}\text{Au} \) as the beam energy increases from 86 to 90 MeV. This information suggests that the new 328.3- and 449.5-keV \( \gamma \) rays observed in this experiment could be assigned to \(^{188}\text{Au} \).

The \( \gamma-\gamma \) coincidence relationships have been analyzed carefully for all the \( \gamma \) rays associated with the 328.3- and 449.5-keV transitions, leading to the newly established band structure in the left panel of Figure 1. The typical coincidence spectrum gated on the 328.3-keV \( \gamma \) ray energy is presented in Figure 2 where most of the \( \gamma \) rays in the band can be seen and the Au K X-rays can be seen also.

### 3 Discussion

#### 3.1 Configuration assignment

The new band in \(^{188}\text{Au} \) shown in Figure 1 exhibits the characteristic of a structure called semidecoupled [11]. Such semidecoupled bands have been systematically observed in odd-odd \(^{182,184,186}\text{Au} \) [4,7,12] nuclei and have been assigned as \( \pi n_2/2 \otimes \nu i_{13/2} \) configurations. The \( \pi n_2/2 \otimes \nu i_{13/2} \) bands for \(^{184,186}\text{Au} \) are also presented in Figure 1 for a systematic comparison. Typical features for such bands are the similar \( \Delta J = 2 \) level spacings. Note that the level spins of the \( \pi n_2/2 \otimes \nu i_{13/2} \) band in \(^{186}\text{Au} \) are increased by one unit compared to the previous assignment [7] on the basis of the level spacing systematics and signature splitting. The new band observed in \(^{188}\text{Au} \) is most probably the analogous band of the same configuration. The spin and parity have been suggested in Figure 1. The configuration assignment may be examined by the quasiparticle alignment process. Figure 3 shows the aligned angular momentum \( I_\pi(h\omega) \) as a function of rotational frequency for the unfavored signature of band in \(^{188}\text{Au} \) and \( \pi n_2/2 \otimes \nu i_{13/2} \) bands in \(^{184,186}\text{Au} \) [4,7]. In this plot, a common reference with Harris parameters \( J_0 = 20h^2 \text{ MeV}^{-1} \) and \( J_1 = 80h^4 \text{ MeV}^{-3} \) has been used. Based on the proposed spin assignment for the band levels in \(^{188}\text{Au} \), a similar alignment pattern has been found for the three bands; that is, all bands have an alignment of about \( 7h \) at \( h\omega = 0.15 \) MeV.

#### 3.2 Properties of the \( \pi n_2/2 \otimes \nu i_{13/2} \) band in \(^{188}\text{Au} \)

A total Routhian surface (TRS) calculation for the favored

![Figure 1](image-url) Level scheme of the \( \pi n_2/2 \otimes \nu i_{13/2} \) bands in (a) \(^{188}\text{Au} \) (this work), (b) \(^{186}\text{Au} \) [7], and (c) \(^{184}\text{Au} \) [4]. The width of arrow, normalized to the (14\(^-\)) \( \rightarrow \) (12\(^-\)) transitions, represents the intensity of \( \gamma \) transition.