Signature partner pairs of superdeformed rotational bands in ^{192}Tl

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Introduction

Rotational bands associated with superdeformed (SD) shapes in $A \sim 190$ mass region are identified by the dynamic moment of inertia ($\Im^{(2)}$), which rises smoothly with the rotational frequency ($\hbar\omega$). This property of SD bands are only observed in the $A \sim 190$ mass region. In lower mass region of $A \sim 130, 150$, pronounced variation of $\Im^{(2)}$ with $\hbar\omega$ is seen. This distinguishing feature of $\Im^{(2)}$ is the result of gradual alignment of $i_{13/2}$ protons and $j_{15/2}$ neutrons. Another characteristic feature of the $A \sim 190$ mass region is that these bands are observed at lower ($\sim 10\hbar$) spins and has smaller transition energies when compared with $A \sim 80, 150$ mass region ($> 20\hbar$). This provide the unique opportunity to study the second potential well. Prediction of ^{192}Hg as the "doubly magic" SD nucleus based on the large gaps in Woods-Saxon single-particle diagram at large deformation supported the fact that multiple SD bands have been found in the neighbouring Hg isotopes [1–4]. Further it was noticed that the various SD bands observed are identical to this "doubly magic" ^{192}Hg SD nucleus. These similarities in the transition energies are explained in terms of pseudo-spin symmetry of SD nuclei [5]. Out of many interesting properties of SD bands observed in $A \sim 190$ mass region, another astonishing property is the observation [6, 7] of "flat bands" in ^{192}Tl, where $\Im^{(2)}$ is observed to be constant with the $\hbar\omega$ in the two bands.

Presently, many theoretical models like Harris ω^2 expansion [8], ab expression [9], variable moment of inertia model [10] etc. are available which provide the reliable spins of SD bands. In the present approach, we have calculated band head MoI of SD bands available in ^{192}Tl in $A \sim 190$ mass region using soft rotor formula (SRF).

Formalism

A nuclear softness (NS) formula was proposed by Gupta [11]. Later Brentano *et al.* [12] given the similar expression for well-deformed nuclei and nuclei in transitional region. Brentano *et al.* called this as "soft-rotor formula" (SRF).

The energy formula for a rigid rotator is given by

$$E = \frac{\hbar^2}{2\Im} I(I+1). \quad (1)$$

This formula predicts state largely higher than obtained from experiments. The variation of MoI with the angular momentum was incorporated and modified Eq. (1) as,

$$E = \frac{\hbar^2}{2\Im_I} I(I+1). \quad (2)$$

After Taylor series expansion of $\Im_I$ about its ground state value $\Im_0$ for $I = 0$ and representing in terms of "Softness" parameter (σ), we get,

$$E_I = \frac{\hbar^2 I(I+1)}{2\Im_0} \frac{1}{(1+\sigma_1 I)} \times \left(1 - \frac{\sigma_2 I^2}{(1+\sigma_1 I + \sigma_2 I^2)} \cdots\right). \quad (3)$$

where, σ_1, σ_2, σ_3... are the constants of first, second, third etc., orders of "nuclear softness".

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Keeping the nuclear softness to only first order i.e putting $\sigma_2, \sigma_3.... = 0$, we get a two parameter formula. Eq. (3) can be written as $(\sigma_1 = \sigma)$,

$$E = \frac{\hbar^2}{2\Im_0} \times \frac{I(I+1)}{1+\sigma I}. \quad (4)$$

where, $\Im_0$ and σ are the fitting parameters. Since, intraband energies and intensities are the only spectroscopic properties whose information are available for superdeformed bands hence one may choose to fit E_γ transitions as.

$$E_\gamma = E(I) - E(I-2). \quad (5)$$

Using Eq. (4) and Eq. (5) the transition energies for superdeformed bands is expressed as

$$E_\gamma(I) = \frac{\hbar^2}{2\Im_0} \times \left[\frac{I(I+1)}{1+\sigma I} - \frac{(I-2)(I-1)}{1+\sigma(I-2)}\right]. \quad (6)$$

The parameters $\Im_0$ and σ are obtained by least-squares fitting.

TABLE I: Parameters $\Im_0$ and σ obtained using least-squares fitting.

SD band	E_γ $(I_0+2 \to I_0)$ (keV)	$\Im_0$ $(\hbar^2 MeV^{-1})$	σ $(\times 10^{-4})$
$^{192}Tl(1)$	283.0	102.73	0.4514
$^{192}Tl(2)$	337.5	102.88	3.3932
$^{192}Tl(3)$	233.4	94.45	20.521
$^{192}Tl(4)$	213.4	94.45	20.598

Results and Discussion

Observed transition energies of $^{192}Tl[1,2,3,4]$, indexed in the table of SD bands [13] and continuously updated ENSDF database [14] have been fitted to SRF model. The values of parameters $\Im_0$ and σ is obtained by fitting of E_γ transition energies in Eq. 6. The calculated band head MoI with SRF formula are almost identical for $^{192}Tl(1)$, $^{192}Tl(2)$ and $^{192}Tl(3)$, $^{192}Tl(4)$ (See Table I).

Conclusion

At low transition energies, the intraband $\gamma-$transitions of one band is close to midpoint energies of adjacent transition of other band suggest that these bands are two pair of signature partner. Identical $(\delta\Im_0/\Im_0 \approx 10^{-3})$ band head MoI obtained using SRF formula for $^{192}Tl(1)$, $^{192}Tl(2)$ and $^{192}Tl(3)$, $^{192}Tl(4)$ verified the experimentally observed signature partners.

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