Influence of pairing correlations on SD bands of ^{130}La and ^{132}Pr in A=130 mass region

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Abstract. We present a systematics for band moment of inertia J_0 and softness parameter σ for super deformed (SD) bands in A=130 mass region by using 4 - parameter formula. We have considered only those SD bands for which spin assignments are available and correspond to 1.5:1 deformation. The σ values of most of the SD bands in this mass region are found to be smaller by 2 orders of magnitude than those of normal deformed (ND) bands. We compared the fitted values of J_0 with those obtained from the measured Q_t values and also with those obtained from the fixed axes ratios. We note that the J_0 values follow the general trend of the prolate rigid rotor curve as a function of mass number A; however a considerable spread exist in this mass region. Many bands appear to have J_0 values smaller than the spherical rigid rotor values, which is very surprising. It suggests that pairing correlations are playing an important role here which leads to decrease in moment of inertia.

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INTRODUCTION

The superdeformed (SD) shapes whose existence was predicted first by V.M. Strutinsky (1) have been observed experimentally by Twin et al. (2). They are manifestation of strong deformed shell effects which remain in close analogy to the well known spherical shell closures. The phenomenon of high spin deformation represents one of the most remarkable discoveries in nuclear physics made during the last decade of 20th century. A large number of SD bands have been observed in the mass region A=60, 80, 130, 150, 190 (3, 4). Also Ideguchi et al. (5, 6) observed SD bands in A=40 mass region. The cascades of SD bands are known to be connected by electric quadrupole (E2) transitions. There is no linking transitions to normal levels so spin assignments of most of these bands carry a minimum uncertainty $\approx$ 1-2 $\hbar$. Recently a link has been observed in A=190 mass region (7). It may be pointed out that a lack of knowledge of the spins has led to an emphasis on the study of dynamical moment of inertia of SD bands and the systematics of the kinetic moment of inertia have not been examined in a detailed manner. Since the SD bands are good rotors, so it was found that moment of inertia of SD bands comes quite close the rigid body value in most of the cases (8, 9). On the other hand, studies of pairing correlations in rapidly rotating nuclei (10) show that pairing fluctuations (11) lead to important renormalization of nuclear motion after the pairing collapse, that is, at rotational frequencies where the normal phase has been realized.

In this paper, we extract the band moment of inertia J_0 and the softness parameter σ of all the known SD bands in A=130 mass region corresponding to 1.5:1 deformation and present their systematics. In this paper, we use a simple 4-parameter formula based on the prescription of Bohr and Mottelson (12, 13) to obtain the band moment of inertia and nuclear softness parameter.

FORMALISM

Bohr and Mottelson (12, 13) pointed out that the rotational energy of $K=0$ band in even -even nuclei can be expanded in power series of $I(I+1)$:

$$\begin{aligned} E(I) &= A((I(I+1))+\frac{B}{A}(I(I+1))^2+ \\ &\quad \frac{C}{A}(I(I+1))^3+\frac{D}{A}(I(I+1))^4) \qquad (1) \end{aligned}$$

The expansion for $K\neq 0$ band can take a form similar to equation (1), but includes a term for the bandhead energy and $I(I+1)$ has to be replaced by $I(I+1)-K^2$. The energy may also be written in different form as (14)

$$\begin{aligned} E(I) &= \frac{1}{2J_0}((I(I+1))-\frac{1}{2}\sigma(I(I+1))^2+ \\ &\quad \sigma^2(I(I+1))^3-3\sigma^3(I(I+1))^4) \qquad (2) \end{aligned}$$

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where the softness parameter $\sigma = \frac{1}{2S(J_0)^3}$ (15) is a small parameter of the expansion with S and J_0 as stiffness constant and moment of inertia respectively. A comparison of equations (1) and (2) suggests that

$$A = \frac{1}{2J_0}, \frac{B}{A} = -\frac{\sigma}{2}, \frac{C}{A} = \sigma^2 \; and \; \frac{D}{A} = -3\sigma^3 \quad (3)$$

For SD bands, where the band quantum number K is not known, the equation (1) can be written as

$$\begin{aligned} E(I) \quad = \quad & E_0 + A(I(I+1) - I_0(I_0+1)) + \\ & B((I(I+1))^2 - (I_0(I_0+1))^2) + \\ & C((I(I+1))^3 - (I_0(I_0+1))^3) + \\ & D((I(I+1))^4 - (I_0(I_0+1))^4) \qquad (4) \end{aligned}$$

where E_0 is the bandhead energy and I_0 is the bandhead spin. Since the bandhead energy and spin are generally not known for the SD bands, one may chose to fit the E2 transitions,

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

Using equations (4) and (5), we obtain

$$\begin{aligned} E_\gamma(I \to I-2) \quad = \quad & A(I(I+1) - (I-2)(I-1)) + \\ & B((I(I+1))^2 - ((I-2)(I-1))^2) + \\ & C((I(I+1))^3 - ((I-2)(I-1))^3) + \\ & D((I(I+1))^4 - ((I-2)(I-1))^4) (6) \end{aligned}$$

The parameters A,B,C and D may now be determined by fitting the E2 transitions for the SD cascades. One may then obtain the nuclear softness parameter (σ) by using the relations in (3).

RESULTS AND DISCUSSIONS

A total of 59 SD bands in this category have been fitted by using the 4- parameter formula. The E2 transitions obtained from the fitting are nearly identical to the experimental values and have a maximum deviation of $\approx 1keV$. The σ values are observed to lie in the range of 0.59×10^{-5} to 91.1×10^{-5}; only 6 cases have values greater than 100×10^{-5} [see Fig .1]. These values are much smaller than those of normal deformed (ND) bands by a factor of 100 at least. The SD bands are, therefore, much more rigid than the ND bands. However, there is some spread in the σ values within the SD bands of a given mass region. The J_0 values from the fitting of SD bands are plotted as a function of the mass number A in the Fig. 2; these are compared with the moment of inertia values of a prolate ellipsoid having x=1.5, and also with that of a rigid sphere. We note that the J_0 values follow the general trend of the prolate rigid rotor as a function

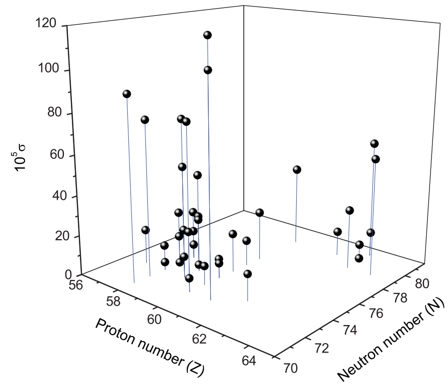

FIGURE 1. The variation of softness parameter σ versus proton number and neutron number in A=130 mass region.

of the mass number A; however considerable spread exists in each mass region. While many values come close to the prolate rigid rotor values, many of them are much below the prolate rigid rotor curve. It is surprising to note that few of them are much higher than the prolate rigid rotor curve [see Fig. 2]. However, many bands appear to have J_0 values even smaller than the spherical rigid rotor values, which is quite surprising. It is very interesting to note in Fig. 2 that in the odd-odd nuclei ^{130}La (SD-1) and ^{132}Pr (SD-1, SD-2, SD-3, SD-4) of A=130 mass region, the fitted values of J_0 are found to be very small as compared to rigid sphere values. We can point out at least three reasons which may lead to such a large spread in the J_0 values. One, the x-values are spread out over a range. Two, the pairing correlations are still playing an important role; presence of pairing leads to a decrease in the moment of inertia. Three, the γ - deformation may also be playing a role in some of the bands; there is evidence of some SD bands being triaxial in shape (16, 17). As the γ-value increases from 0° to 60° (from prolate to oblate), the rigid body moment of inertia is known to decrease. We have, however, excluded the known triaxial SD bands from our studies. Further insight into the behavior of band moment of inertia may be obtained by a comparison of the J_0 values from the band fitting with those obtained from the Q_t measurements and hence the axes ratio (x) [see Fig. 3]. In Fig. 3, J_0 values of those SD bands are compared in which Q_t measurements are available. The J_0 values distinctly follow the trend of the values extracted from the Q_t measurements; however, these are smaller by about $10-20\%$ in a number of cases; sometimes these come close to the rigid sphere values. There are many cases where J_0 values are less than the

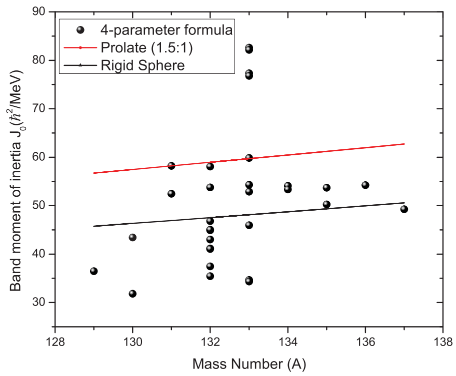

FIGURE 2. Band moment of inertia J_0 as a function of mass number A for SD bands in A=130 mass region with (1.5:1) deformation obtained by using the 4-parameter formula. The black line is the moment of inertia value for rigid sphere and red line for prolate ellipsoid with deformation (1.5:1)

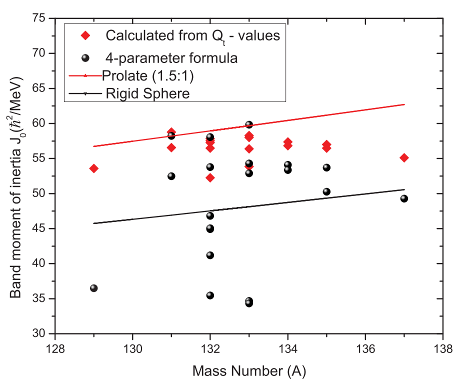

FIGURE 3. Individual values of band moment of inertia J_0 as obtained from the measured Q_t values are compared with the values obtained from the 4-parameter fits. The curves for 1.5:1 and 1:1 shapes are also shown.

rigid body values can be explained in terms of residual pairing correlations.

CONCLUSIONS

The 4-parameter formula has been used to obtain the band moment of inertia J_0 and the softness parameter σ for SD bands in A=130 mass region corresponding to 1.5:1 deformation. The nuclear softness parameter σ for SD bands lies in the range of $10^{-3} \leq \sigma \leq 10^{-6}$ as compared to ND bands (15) having a range of $10^{-2} \leq \sigma \leq 10^{-4}$. The nuclear softness parameter is related to extent of rigidity of SD bands. Thus, the SD bands are found to be much more rigid than the ND bands. A significant spread, particularly below the appropriate rigid rotor values suggests the existence of residual pairing effects. It is very interesting and surprising too that in odd-odd nuclei of A=130 mass region, the pairing is playing an important role due to which the fitted values of J_0 are found to be very small as compared to rigid sphere values.

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