Pairing correlation in the "flat bands" of the superdeformed Pb nuclei

H. M. Mittal* and Anshul Dadwal
Department of Physics,
Dr. B.R. Ambedkar National Institute of Technology,
Jalandhar 144011, INDIA

Introduction

High spin phenomena of superdeformation was proposed many years ago to explain the fission isomers observed in the actinide nuclei. These nuclei are trapped in a metastable minimum associated with a very elongated ellipsoidal shape having axis ratio close to 2 : 1. These theoretical prediction were confirmed experimentally when the first discrete-line superdeformed (SD) states were found in the $A \sim 150$ mass region of the ^{152}Dy nucleus [1]. These exotic nuclear shapes with large deformation ($\beta \sim 0.5$) are stabilized through microscopic shell effects. The first observation of SD bands in $A \sim 190$ mass region was reported in ^{191}Hg and nowadays, more than 80 SD bands have been reported in this mass region [2]. Superdeformation spectroscopy has provided us with much information regarding the behaviour of MoI in SD nuclei. Two types of MoI characterize nuclei in SD states, viz. kinematic ($\Im^{(1)}$) and dynamic MoI ($\Im^{(2)}$). Since $\Im^{(1)}$ depends upon the spin proposition, $\Im^{(2)}$ is frequently studied in SD states. A smooth rise of $\Im^{(2)}$ with increasing rotational frequency ($\hbar\omega$) is observed in the $A \sim 190$ mass region which is interpreted as the alignment of both high-N quasiprotons and quasineutrons and reduction in pairing. An interesting feature of $\Im^{(2)}$ in the $A \sim 190$ mass region is the observation of "flat bands" in ^{192}Tl where $\Im^{(2)}$ does not display a rise with $\hbar\omega$. Later, flat bands were found in odd-A isotopes of Pb which have nearly constant dynamic MoI as the function of rotational frequency

*Electronic address: `mittal.hm@lycos.com`

Formalism

An exponential dependence of MoI on pairing correlations was first proposed by the phenomenological studies of Draper [3]. Later Ma and Rasmussen [4] carried out the cranking model calculations of MoI for a range of values of the pairing parameter (Δ). Ma and Rasmussen [4] also concluded that the pairing does not completely disappear even at the critical spin. A similar conclusion was made by Sood and Jain [5] using single particle level densities. The rotational energy expression given by Sood and Jain [5] is

$$E(I) = \frac{\hbar^2}{2\Im} I(I+1) e^{\Delta_0 \sqrt{1-\frac{I}{I_c}}}. \qquad (1)$$

Keeping $\Im$ and Δ_0 as free parameters and fixing critical spin $I_c = 85\hbar$, the exponential model was applied to the SD bands of the $A \sim 190$ mass region [7].

Results and Discussion

Using the intraband $\gamma-$transition energies [2], the fitting parameters of nine flat SD bands of Pb ($^{193}Pb(1,2,9)$, $^{195}Pb(1,2)$, $^{197}Pb(1,2,3,4)$) are calculated. The systematic study of these bands using exponential model reveal very significant results. For flat bands $^{193}Pb(1,2,9)$, the effective pairing parameter Δ_0 is very negligible $\approx 0.1 - 0.2$ (see table I). Just as ^{193}Pb isotope, the SD band $^{195}Pb(1,2)$ also does not show the rise in $\Im^{(2)}$ with $\hbar\omega$. For flat bands $^{195}Pb(1,2)$, the value of Δ_0 is in coincidence with the Δ_0 obtained for the flat bands of ^{193}Pb, where Δ_0 is almost negligible. It is worth noting that for SD band $^{195}Pb(2)$, Δ_0 is zero. Similarly four flat bands $^{197}Pb(1,2,3,4)$ were also observed in ^{197}Pb. The Δ_0 parameter obtained for flat bands in

^{197}Pb are in accordance with the Δ_0 parameter of other odd-A isotopes ($\Delta_0 \sim 0.1 - 0.2$). Apart from these nuclei of the $A \sim 190$ mass region, the flat bands are also available in ^{192}Tl [6]. Motivated by the almost negligible effective pairing parameter obtained for flat bands of Pb nucleus, we have also calculated the pairing parameter of $^{192}Tl(1,2)$. The almost negligible values of Δ_0 obtained for flat bands $^{192}Tl(1,2)$ are in coincidence with the values obtained for flat bands of the Pb nucleus. The pairing parameter, Δ_0, is an effective pairing parameter which may include a contribution from the Coriolis antipairing effect as well as from the higher order cranking effect [7]. Since the static pairing correlation is generally very different for different configurations (e.g. between even and odd nuclei) [8], it was proposed that Δ_0 parameter could be analogous to the dynamic pairing correlation because similar Δ_0 parameter was obtained for the identical SD bands of the $A \sim 190$ mass region [9].

TABLE I: The parameters obtained using the exponential model for the 9 flat SD bands of odd-A Pb isotopes in $A \sim 190$ mass region. Here $1, 2...$ in the parenthesis represent band 1, band 2...,respectively. The band-head spins (I_0) have been taken from for Ref. [10]. The χ is the RMS deviation between the calculated and experimental transition energies.

SD Band	E_γ^{exp} (keV)	I_0 ($\hbar$)	Δ_0	$\Im$ ($\hbar^2$MeV^{-1})	χ $\times 10^{-3}$
$^{193}Pb(1)$	277.0	11.5	0.186	111.3	1.9
$^{193}Pb(2)$	190.2	7.5	0.056	98.9	3.9
$^{193}Pb(9)$	212.9	8.5	0.198	112.6	3.2
$^{195}Pb(1)$	141.8	5.5	0.097	108.2	0.8
$^{195}Pb(2)$	162.2	6.5	0.000	98.2	2.4
$^{197}Pb(1)$	142.6	5.5	0.114	108.7	0.8
$^{197}Pb(2)$	123.0	4.5	0.051	101.7	3.9
$^{197}Pb(3)$	200.1	8.5	0.109	109.1	4.1
$^{197}Pb(4)$	221.8	9.5	0.128	111.0	1.7

Conclusion

A reliable phenomenological analysis of the 9 flat SD bands of odd-A isotopes of Pb, ^{193}Pb, ^{195}Pb, ^{197}Pb, are made using the two parameter exponential model with pairing attenuation. The effective pairing parameter Δ_0 obtained using exponential model for flat bands reveals very astonishing results. For flat bands the Δ_0 parameter, which may be analogous to the dynamic pairing parameter, obtained is $2-3$ times (for few bands, $7-9$ times) smaller than the SD bands for which $\Im^{(2)}$ rises smoothly with increasing $\hbar\omega$ within the same isotope. According to the Mottleson-Valatin effect [11], the static pairing is quenched in the SD bands and any remaining correlations are speculated to be of dynamic character [8]. The observation of almost negligible pairing parameter for the flat bands of the $A \sim 190$ mass region shows that the static and dynamic pairing correlations do not play a significant role for flat bands in the evolution of $\Im^{(2)}$ with increasing $\hbar\omega$.

Acknowledgments

Financial support from Department of Science and Technology (Govt. of India) is gratefully acknowledged.

References

[1] P. J. Twin *et al.*, Phys. Rev. Lett. **57**, 811 (1986).
[2] http://www.nndc.bnl.gov/
[3] J. E. Draper, Phys. Lett. B **41**, 105 (1972).
[4] C. W. Ma and J. O. Rasmussen, Phys. Rev. C **9**, 1083 (1974).
[5] P. C. Sood and A. K. Jain, Phys. Rev. C **18**, 1906 (1978).
[6] Y. Liang *et al.*, Phys. Rev. C **46**, R2136 (1992).
[7] S. N. Zhou and C. Zheng, Phys. Rev. C **55**, 2324 (1997).
[8] Y. R. Shimizu, Nucl. Phys. A **520**, 477c (1990).
[9] A. Dadwal and H. M. Mittal, Eur. Phys. J. A **53**, 132 (2017).
[10] A. Dadwal and H. M. Mittal, Physical Review C (under review).
[11] B. R. Mottelson and J. D. Valatin, Phys. Rev. Lett. **5**, 511 (1960).