Empirical Rule for Pair Break Mechanism in Three-quasiparticle Rotational Bands

Sukhjeet Singh[1*], Sushil Kumar[1], A.K. Jain[2], and J.K. Sharma[1]
[1]Department of Physics, Maharishi Markandeshwar University, Mullana -133 207(India)
[2]Department of Physics, Indian Institute of Technology, Roorkee-247667(India)
*email: dhindsa_ss@yahoo.com

An empirical rule, on the basis of odd-even mass difference Δ_{oe}, is suggested for breaking of a proton pair or a neutron pair in odd-A nuclei to form a lower lying three-quasiparticle (3qp) configuration. The proton Δ_p and neutron Δ_n pairing gaps are calculated using four point formula [1]. On the basis of present calculations, we are able to point out the breaking of a particular pair in the lowest lying 3qp state. The generalization of this rule to configuration dependent pairing energy calculations and hence its applications for configuration assignments to three-quasipartcile bands are also discussed.

We can calculate the proton and neutron pairing energies i.e. Δ_p and Δ_n respectively, using the four-point formula [1, 2]:

$$\Delta_n^4(N) = \frac{(-1)^N}{4}[B(Z,N-2) - 3B(Z,N-1) + 3B(Z,N) - B(Z,N+1)] \quad ....(1)$$

$$\Delta_p^4(Z) = \frac{(-1)^Z}{4}[B(Z-2,N) - 3B(Z-1,N) + 3B(Z,N) - B(Z+1,N)] \quad ....(2)$$

where $B(N,Z)$ are binding energies. The experimental values of the binding energies can be used to calculate a proton and a neutron pairing gaps for given nuclide [3].

Results and Discussions

On the basis of present calculations, we are able to propose an empirical rule for pair break mechanism. According to this rule, if Δ_p is smaller than Δ_n, the proton pair breaks; on the other hand, if Δ_n is smaller than Δ_p, the neutron pair breaks down and forms a lower lying 3qp configuration in an odd-A nuclide as shown in Table 1. In order to confirm the validity of this empirical rule of pair break mechanism in rare earth region (153<A<187), we calculated proton (Δ_p) and neutron (Δ_n) paring gaps, by using four point formulae given by equation (1) & (2). In these calculations, we used experimental values of the binding energies [3]. The present empirical rule is tested for 50 lowest lying 3qp structures in 50 different nuclides [4]. Out of these 50 different 3qp configurations, there are 32 three-quasiparticle bands which directly obey this empirical rule and for remaining 18 cases, it is not possible to predict the breaking of a particular pair because of following reasons:

(a) The uncertainty in proton and neutron pairing gaps is larger than the difference between Δ_p and Δ_n.
(b) The configuration of a lowest lying 3qp band is not pure.
(c) The magnitude of both pairing gaps is comparable.
(d) The lowest lying 3qp configurations involve high-*j* orbitals and there is a competition between pairing and Coriolis (anti-pairing) effect.

It is natural to expect that in odd-Z nuclei a neutron pair breaks and in odd-N nuclei a proton pair breaks. However this natural observation is not obeyed in all the observed cases. There are many examples that have odd-Z and/or odd-N and are not in accordance with natural rule but satisfy the present empirical rule of pair break mechanism as shown in 3rd to 5th rows of Table 1. There are certain 3qp bands which have more than one competing configurations, and the experimental information for distinction among these competing configurations is not sufficient. In these 3qp bands, the present empirical rule of pair break mechanism will be useful for experimentalists to distinguish among the competing configurations as given in the 6th row of Table 1. On the basis of present calculations, we also pin-point that if difference between proton and neutron pairing gaps is larger than 300 keV, the pair (proton or neutron) having lower value of pairing energy will keep on breaking, for example ^{177}Lu, ^{175}Lu, ^{179}Re and ^{181}Re [4]. Out of these four nuclides, ^{177}Lu, is quite interesting example which has $\Delta_p - \Delta_n = 402.2 keV$ and has total 15 three-quasineutron configurations [4]

Conclusions

An empirical rule on the basis of odd-even mass difference Δ_{oe} is tested for pair breaking of a proton pair or a neutron pair in odd-A nuclei to form a lower lying 3qp configuration. According to this rule, if Δ_p smaller than Δ_n, the proton pair breaks; on the other hand, if Δ_n smaller than Δ_p, the neutron pair breaks down and form a 3qp configuration. This rule will be useful for configuration assignment to those 3qp bands which have more than one competing configurations and experimental information for distinction among these competing configurations is not sufficient.

The financial support from Department of Science and Technology, Govt. of India is gratefully acknowledged.

References

[1] Bohr and Mottelson, Nuclear Structure Vol.1, W.A. Benjamin, INC (1987).
[2] M. Bender *et al.* Eur. Phys. J. A **8**, 59 (2000)
[3] G. Audi and A.H. Wapstra, Nucl. Phys. A 595, 409 (1995).
[4] Sukhjeet Singh, *et al.* At. Data & Nucl. Data Tables 92, 1 (2006).

Table 1

Nucleus	K	Configuration	Δ_p(keV)	Δ_n(keV)	Pair Break	Ref.**
$^{181}_{75}Re_{106}$	15/2+	$5/2[402]_\pi \otimes 9/2[624]_\nu \otimes 7/2[514]_\nu$	890.0	793.5	Neutron	2000Pe18
$^{177}_{72}Hf_{105}$	23/2+	$9/2[514]_\pi \otimes 7/2[404]_\pi \otimes 7/2[514]_\nu$	666.3	758.0	Proton	1998Mu14
$^{183}_{75}Re_{108}$	15/2+	$9/2[514]_\pi \otimes 5/2[402]_\pi \otimes 1/2[541]_\pi$	552.0	667.0	Proton*	2000Pu01
$^{177}_{73}Ta_{104}$	13/2-	$1/2[541]_\pi \otimes 5/2[402]_\pi \otimes 7/2[404]_\pi$	598.0	742.0	Proton*	2000Da09
$^{177}_{73}Ta_{104}$	21/2-	$9/2[514]_\pi \otimes 7/2[404]_\pi \otimes 5/2[402]_\pi$	597.0	742.0	Proton*	2000Da09
$^{177}_{73}Ta_{104}$	17/2+	$9/2[514]_\pi \otimes 7/2[404]_\pi \otimes 1/2[541]_\pi$	598.0	742.0	Proton*	2000Da09
$^{179}_{73}Ta_{106}$	21/2-	$5/2[402]_\pi \otimes 7/2[404]_\pi \otimes 9/2[514]_\pi$ $9/2[514]_\pi \otimes 7/2[514]_\nu \otimes 5/2[512]_\nu$	875.0	581.5	Neutron	1997Ko13

* Configuration dependent pairing energy calculations
**Nuclear Science Reference key numbers are given in last column