Analysis of parity doublet in medium mass nuclei

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Introduction

Although the nuclear shape co-existence for various mass regions of the periodic table is a well known phenomena, it remains an interesting investigation till today. On the other hand, the existence of parity doublet is relatively new [1]. The origin and manifestation of such an interesting observable is not yet known clearly. It is reported that the parity doublet is not visible in a nucleus with normal deformation or spherical in shape. However, the existence of parity doublet is possible for nuclei with highly deformed or superdeformed shape. In this case, two orbitals with opposite parity lie very close to each other. Since, the parity doublet is only appeared in superdeformed configuration and not in normal or spherical shape, the possibility of its origin may be related to its shape, i.e. with deformed orbitals. That means, in normal situation, the high lying partner of the doublet does not come nearer to the low lying one when the nucleus gets deformed, gives rise a Nilsson like structure in the superdeformed state. The shape co-existence, i.e., two different shapes with very close in energy is also a rare, but known incident in nuclear structure physics [2]. In this case, both the solutions are nearly or completely degenerate (different configuration with same energy). This phenomenon is mostly visible in the mass region $A = 100$ of the periodic table[3].

Here, we have chosen Zr nucleus as a potential candidate both for shape co-existence and study of parity doublets using the well known relativistic mean field (RMF) formalism[4] and to take care of the pairing correlation, the constamt gap BCS-approch is used in our calculations.

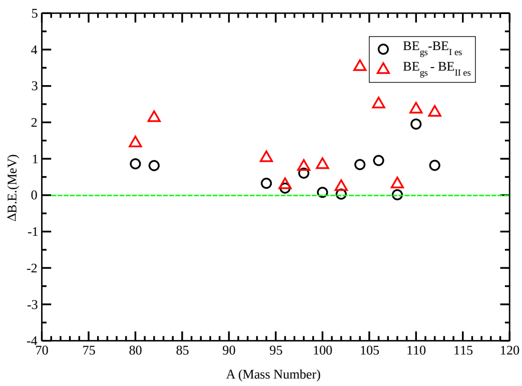

FIG. 1: The Shape co-existence for Zr isotopes.

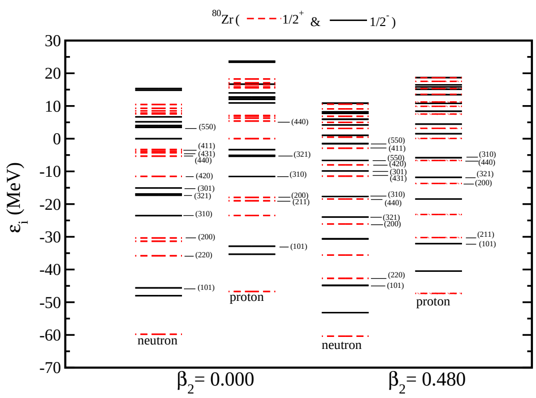

FIG. 2: Single - particle levels for ^{80}Zr in normal and superdeformed states.The single - particle levels are denoted by the Nilsson indices [N, n_z, Λ]Ω^{π}.

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1. Results and Discussion

The binding energy difference between the ground and first and second intrinsic excited states are shown in Fig.1 for Zr isotopes. The solid line is the zero reference label, which marks the shape co-existence line. The points which are on the line are designated as perfectly shape co-existence nuclei. In the present work, we would like to show that not only the neutron-deficient Zr isotopes have shape co-existence, but also other normal and neutron-rich Zr isotopes have low-lying superdeformed configuration including the normal/spherical shape. There are many isotopes (^{96,98,100,102,108}Zr), which have $\Delta BE \leq 1$MeV for both cases like 1^{st} and 2^{nd} intrinsic excited states. These type of shape co-existence called triple shape co-existence [3]. If we see the ΔBE for ^{108}Zr in Figure 1, its excited state has almost same energy with its ground state, leading to the phenomena of shape co-existence. The shape co-existence are very important in the reaction study because surface density distribution plays a crucial role in the cross-section and it will change by applying small perturbation in energy.

The parity doublets for the superdeformed solutions are clearly seen in Figs. 2, where excited superdeformed configurations for ^{80}Zr are given. As shown in Figure 2, the energy level for spherical shape for opposite parity are well separated from each other, but becomes closer with deformation which shows the parity doublets in the system. For example, in case of ^{80}Zr, if we plot the single particle energy level for neutron, then the energy levels $[310]\frac{1}{2}^-$ and $[440]\frac{1}{2}^+$ are far from each other ($\sim$ 18.28 MeV), but becomes almost degenerate ($\sim$ 1.28 MeV) at superdeformation (β_2 = 0.480). Same behavior we found in the single particle energy orbits $[440]\frac{1}{2}^+$ and $[310]\frac{1}{2}^-$ of proton intrinsic single particle energy distribution, i.e. in normal deformation, these two levels are separated from each other by 16.8 MeV, but in superdeformed case (β_2=0.480), it becomes closer ($\sim$ 0.5 MeV).

2. Summary and Conclusion

We calculate the ground and low-lying excited state properties, like binding energy and quadrupole deformation parameter β_2 using RMF(NL3) formalism for Zr isotopes, near the drip-line regions. We are getting the double and triple shape co-existence from our analysis in some Zr isotopes which consistent with the earlier data.The present prediction of parity doublet may be a challenge for the experimentalists to look for such configuration states. In general, we find large deformed solutions for the neutron-drip nuclei which agree with the experimental measurements. In the present calculations, a large number of low-lying intrinsic superdeformed excited states are predicted in many of the isotopes, which show the parity doublet near the Fermi levels. The parity doublet levels are nearly degenerated in excited states which can make the two different parity band by transition of two particles from reference frame to these degenerate opposite parity levels. It may be solved the problem of existence of the twin bands and quantization of alignments of shapes. This analysis will help us to understand the intrinsic excited states of the Zr and other similar isotopes. In this respect, some more calculations are required to build a general idea about the omega parity doublets.

References

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