Evaluation of shapes and search of shape coexistence in $^{80-110}$Zr

M. Aggarwal[1*] and G. Saxena[2]
[1]Deptartment of Physics, University of Mumbai, Mumbai - 400098, INDIA. and
[2]Department of Physics, Govt. Women Engineering College, Ajmer - 305002, INDIA.

Introduction

Nuclear shapes are very sensitive to the structural effects and can change with spin, isospin and temperature. In some cases configurations corresponding to different shapes may coexist at similar energies which may arise from intruder excitations [1] leading to shape coexistenxe which is a topic of recent research interest. The nuclear masses around A≈ 80-110 offer an interesting region to explore ground state shape changes and shape coexistence in the vicinity of Z around 40 and then transition towards less deformed to spherical while approaching shell closure at Z = 50. Most of the atomic nuclei are known to have spherical or prolate ground state shapes except in few regions on the nuclear chart where oblate and triaxial shapes [2] are predominant. We evaluate shapes in the Z=40 region in a theoretical framework and search for shape coexistence.

Brief description of work

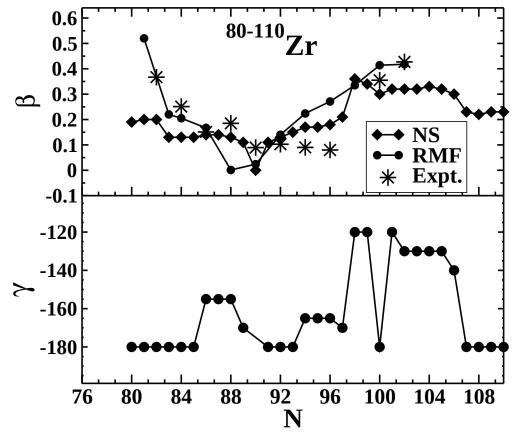
Calculations are performed within the framework of (i) Nilson Strutinsky (NS) method [3] using triaxially deformed Nilsson potential including shell corrections where the classical collective properties of the liquid drop model are combined with the quantum corrections due to shell effects (ii) relativistic mean-field plus state dependent BCS approach (RMF+BCS). Results of both the theories are compared with the available experimental data. In NS method, Strutinsky formalism is used by incorporating higher order corrections with Hermite polynomials. The energy minima are traced using NS method (for Nilsson deformation parameters β and γ where various γ are competing for E minima) and RMF+BCS appraoch (using NLSH and TMA parameters).

*Electronic address: mamta.a4@gmail.com

Results and Discussion

Fig. 1 shows (a) β vs N (b) γ vs. N for Zr isotopes. In Fig. (a), both the theories agree well with the experimental values [5]. Zr presents an entire range of a highly deformed oblate near proton drip line to triaxial while moving towards spherical around Z=50 to highly deformed prolate in A=100 region. Triaxiallity (Fig. 1(b)) dominates in this region with some oblate (-180^o) and few prolate shapes(-120^o). There are slight deviations in NS and RMF predicted β values at some places which could be due to inclusion of triaxiality in NS calculations, whereas in RMF+BCS calculations, only prolate and oblate shapes have been included. Dominance of triaxial shapes in this region justifies the slight deviation in values.

Fig. 2 shows energy minima as a function of β using (a) RMF+BCS and (b) NS aproach for various γ ranging from oblate to prolate with triaxial shapes. RMF+BCS predicts oblate shape with 0.2 deformation in ^{84}Zr. The prolate minima is seen well above the oblate minima by around 1 MeV. In Fig. 2(b), we note various γ are competing for E minima with two γ -180^o (oblate) and -155^o (triaxial) coexisting with the deepest minima at almost the same energy. The triaxial shape (-155^o) differs from the oblate shape by merely 173 KeV. The prolate shape (γ=-120^o) is well above the other γs and lies around 1 MeV above the oblate shape in agreemnet with RMF+BCS. Hence both the theories predict Oblate minima with prolate lying at around 1 MeV above



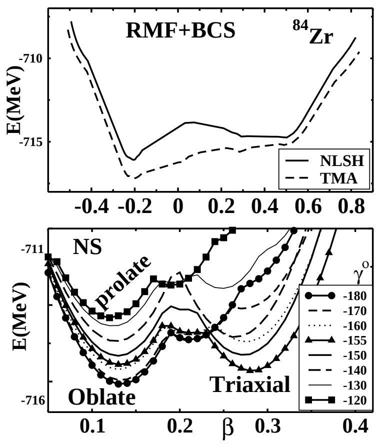


FIG. 2: E vs. β with (a) RMF+BCS (b) NS method for ^{84}Zr

oblate shape. Inclusion of triaxiallity adds one additional degree of freedom which paves its way to the intersting phenomena of shape coexistence. In Fig. 1(b), ^{100}Zr shows oblate minima (β=0.32) which is actually coexisting with prolate shape with merely 31 Kev energy difference in accord with the RMF+BCS which also shows oblate minima (β=0.323). However the prolate minima in RMF+BCS lies at 1 MeV above the oblate minima.

Conclusion

Evaluation of shapes and the phenomena of shape coexistence is studied by employing RMF+BCS and Nilsson Strutinsky approach. Triaxial shape is dominant in Z=40 (A ≈80-100) region with some oblate and few prolate shapes consisting of highly deformed (with β=0.4-0.5) as well as spherical nuclei. ^{84}Zr shows coexisting oblate and triaxial minima with prolate minima lying around 1 MeV above the oblate minima. Predictions of both the theories are in consensus except few differences due to inclusion of triaxiality in NS approach. Nilsson Strutinsky approach predicts shape coexistence with oblate and prolate in ^{100}Zr.

Acknowledgments

Authors M. Aggarwal and G. Saxena thank DST, SERB for support under WOS-A and YSS/2015/000952 respectively.

References

[1] P. J. Woods and C. N. Davids, Annu. Rev. Nucl. Part. Sci. 47, 541 (1997).

[2] Mani Varshney et al., Phys. Scr. 75, No. 4, 451 (2007).

[3] Mamta Aggarwal, Phys. Rev. **C 89**, 024325 (2014).

[4] G. Saxena et al., Int. Jour. Mod. Phys. E 22 (2013) 1350025; Physics of Atomic Nuclei **80**, (2017) 211.

[5] S. Raman et al., At. Data Nucl. Data Tables 36, 1 (1987).