Magic numbers of superdeformed nuclei using Nilsson potential

Poonam Jain[1], Uma. V. S[2], and Alpana Goel[3*]
[1,3]*Amity Institute of Nuclear Science and Technology (AINST), Amity University, Noida-201303, INDIA and*
[2]*Department of Physics,Amity Institute of Applied Science (AIAS), Amity University, Noida-201303, INDIA*

Introduction

The study of the atomic nucleus is a complex arrangement of constituent neutrons and protons. Theoretical and experimental finding and the apparent success of shell model were some of the cornerstones of nuclear structure physics.

Inspite of important prediction of the magic numbers, the shell model has been very successful in predicting the ground state spin and parity of a large number of odd-A nuclei. The angular momentum is determined by the level occupied by the last unpaired nucleon [1].

In the ground state most of magic numbered nuclei are spherical, prolate or possible triaxial and very few cases of really oblate nuclei have been found experimentally. Since long the Nilsson proposed a deformed shell model for the nucleus considering it as spheroid that may either be prolate or oblate. Due to rotation effect, nuclei undergoes certain changes in shapes as prolate, oblate or possible triaxial and strongly elongated etc. Further advancement in deformed nuclei for highly elongated nuclei corresponding to a high deformation are called super deformed (SD).

Over past decades, the studies of super deformed (SD) rotational bands in nuclei have been focused on experimental and theoretical efforts. SD nucleus is considered to have the shape of a prolate axially-symmetric ellipsoid with an axis ratio of $\approx 2:1$ for the major to minor axes. The shell structure of super deformed nuclei exhibits new shell closures corresponding to new magic numbers which give rise to the stabilization of such shapes [2].

Further extensive data have been obtained for SD nuclei by many physicist. A large variety of different phenomena were used to infer the special stability of the magic numbers [3].

These SD band are characterized by cascades of regularly spaced pattern, stretched quadrupole transition, and elongated ellipsoidal shapes which are stabilized by shell gaps in the single-particle energy spectrum [4, 5]. In this work, energy gaps are calculated using Nilsson potential.

Theoretical Framework

The super deformation at high angular momentum remains one of the most interesting and challenging topics of nuclear structure. The aim of our work is to investigate the influence of fast rotation on nuclear shell structure. Using Nilsson model, we search for large gaps in the spectra and simultaneously for those nuclear spins at which the gaps occur.

We use Nilsson model potential which comprises the anisotropic harmonic oscillator potential plus the spin-orbit and centrifugal potentials. It is defined as

$$H_o = H_o^o + H_\delta \ , \qquad (1)$$

where the first and the second term on the R.H.S. stand for the spherical and the deformed part respectively. Now the total Hamiltonian is rewritten as

$$H_o = H_o^o + H_\delta + C\,\overrightarrow{l}.\overrightarrow{s} + D\,\overrightarrow{l}^2. \qquad (2)$$

Here, the constant C gives the strength of spin-orbit force and $D\,\overrightarrow{l}^2$ shifts the levels with higher l values downwards; the last term makes the harmonic oscillator potential resemble a realistic flat bottom potential.

*Electronic address: agoel1@gmail.com

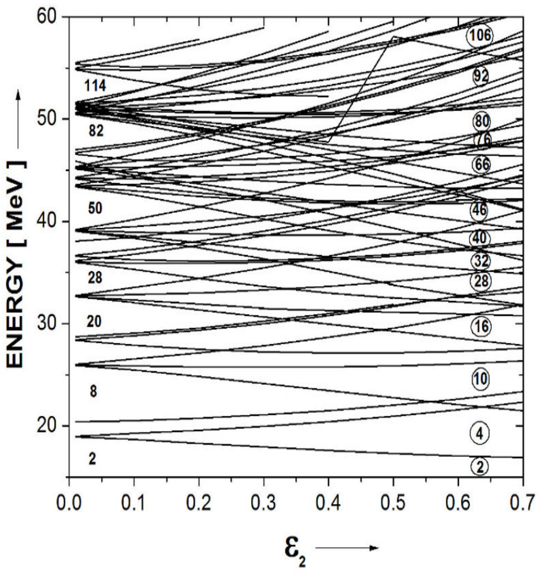

FIG. 1: Energy with respect to deformation is plotted for ratio 2 : 1 at 0.6.

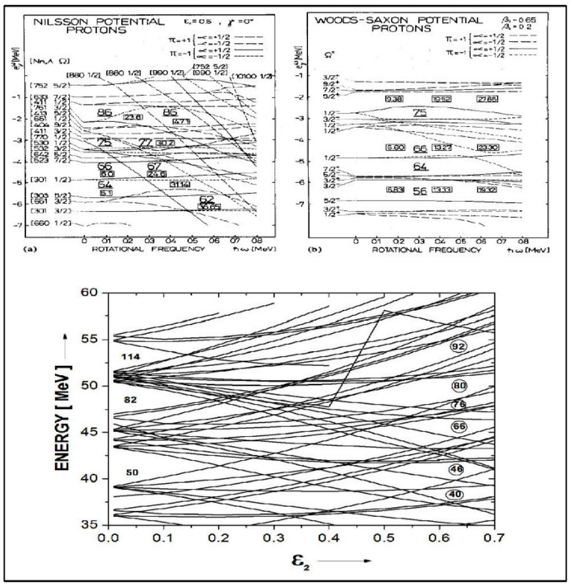

FIG. 2: The comparison of our result with Nilsson cranked potential and Wood-Saxon potential is shown.

Results and discussion

We have analyzed the single particle states in strongly elongated nuclei with a quadrupole deformation $\beta \approx 0.6$ (axis ratio $\sim 2:1$). It can be seen that large energy gaps give rise to deformed "magic" number over a range of deformations. Such numbers are marked in Figure [1] by circle. We are able to identify the most probable SD magic numbers $Z{=}2, 4, 10, 16, 28, 32, 40, 46, 66, 76, 80, 92, 106$ are generated at large elongations by Nilsson potential.

Also in Figure [2], we compared single particle spectrum using Nilsson potential with Dudek et al. [4] in which the energies of single particle orbitals in a deformed Wood-Saxon potential and Nilsson cranked potential are plotted as a function of prolate quadrupole deformation β for both neutrons and protons.

The calculations indicate that at large nuclear elongations, corresponding to an axis ratio (of axially symmetric shapes) of about $2:1$, strong shell effects are expected at above mentioned Z values. Above all our results provide the excellent agreement between the calculated results and those predicted by the Ref. [2–5].

Overall, our model result has been analyzed using Nilsson potential and obtained the magic numbers for superderformed nuclei. Also the energy gaps obtained by Nilsson potential are in good agreement with the results of Nilsson cranked potential and Wood-Saxon potential.

References

[1] A. Bohr and B. R. Mottelson, Nuclear Structure (Benjamin, Reading, MA) **Vol. II**, (1975).

[2] U. Garg and B. Kharraja, PINSA, **66**, A, No.6, 545-563 (2000).

[3] N. Sharma et al., Phys. Rev. C **87**, 024322 (2013).

[4] J. Dudek et al., Phys. Lett. **112B**, 1 (1982).

[5] S. Aberg et al., Nucl. Phys. A **557**, 17c-38c (1993).