Breaking of neutron magicity at ^{40}Mg

R. Sharma[1,2],* S. K. Jain[1], G. Saxena[3], and Mamta Aggarwal[4]
[1]*Department of Physics, School of Basic Sciences, Manipal University Jaipur, Jaipur-303007, India*
[2]*Department of Physics, S. S. Jain Subodh P.G.(Autonomous) College, Jaipur-302004, India*
[3]*Department of Physics, Govt. Women Engineering College, Ajmer - 305002, India and*
[4]*Department of Physics, University of Mumbai, Kalina, Mumbai-400098, India*

It is now universally accepted that the nuclei with even number of neutrons and protons are more stable than those with odd numbers. In particular, there are a few neutrons and protons which have exceptional stability, known as magic numbers. Near or on the stability line, there is a well known and accepted series of magic numbers, but for exotic nuclei away from the stability line or on the drip-lines this conventional series does not hold good.

Due to various efforts on experimental and theoretical fronts on drip line nuclei, our understanding of the nuclear structure has been pushed towards a new horizon of exotic phenomena. One such phenomenon is the disappearance of the conventional magic numbers like N=8, 20, and 28 [1, 2] and the emergence of new magic numbers like N=14, 16, 32, 34, and 40 [3–5] near the drip lines. Since the neutron-rich N=28 nuclei, now accessible experimentally [6], play an important role in the nucleosynthesis of the heavy Ca-Ti-Cr isotopes, it is crucial to know if the magicity of N=28 persists or breaks in neutron-rich region. Recent mass measurement and spectroscopic experiments have shown that N=28 shell closure is weakened in Mg, Si, S and Ar isotopes. Here, we focus on the breaking of neutron magicity in N=28 isotones. We have calculated the deformation and neutron single particle energies for N=28 isotones in proton deficient side with the help of Relativistic mean-field (RMF) approach using density-dependent meson-exchange (DD-ME2) [7] and density dependent point coupling (DD-PCX) [8] force parameters.

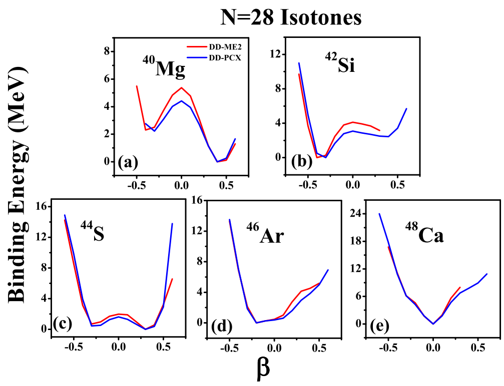

FIG. 1: The potential energy surfaces for ^{40}Mg, ^{42}Si, ^{44}S, ^{46}Ar, and ^{48}Ca calculated by using DD-ME2 [7], and DD-PCX [8] parameters are shown in (a), (b), (c), (d) and (e), respectively.

To demonstrate the breaking of magicity in N=28 isotones, we have plotted the potential energy surfaces in Fig. 1 as a function of the quadrupole deformation parameter (β). Here, the binding energy is normalized with respect to the global minima. Figs. (a), (b), (c), and (d) show that the N=28 isotones are well deformed on the lower Z side (neutron rich side) in contrast to zero deformation for ^{48}Ca. This shows that the N=28 shell closure shows somewhat different character towards neutron drip line for nuclei with Z<20. In Fig. 1 (a) it is clearly shown that ^{40}Mg has a large prolate deformation minimum (β=0.4) in addition to the oblate shapes of ^{42}Si and ^{46}Ar with β=-0.4 and β=-0.2, respectively. The interesting phenomenon of shape coexistence is observed in neutron-rich ^{44}S where two energy minima of oblate and prolate shape with a

*Electronic address: rina.physics1@gmail.com

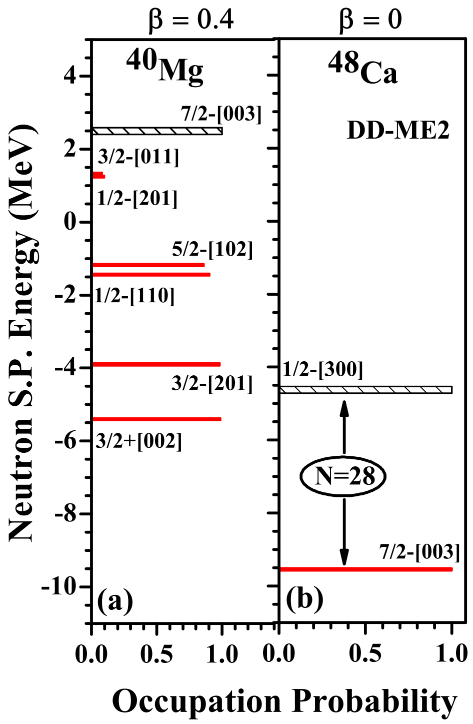

FIG. 2: Neutron single particle energy (MeV) for nuclei with ^{40}Mg and ^{48}Ca obtained from RMF approach using DD-ME2 [7] parameter.

transition energy of 0.69 MeV are seen. A sudden change from oblate to spherical shape is observed while one moves from ^{46}Ar to ^{48}Ca. It is noticeable here that our both the force parameters DD-ME2 and DD-PCX are in good match and show same kind of shapes and deformation.

In continuity to further examine the result of our calculation in Fig. 2, we have shown the Nilsson neutron single particle energies along with the occupation probability of the states using DD-ME2 parameter for ^{40}Mg and ^{48}Ca. For both the considered nuclei, deformation is also mentioned on the top of the panels. All the states are shown with their quantum numbers where filled states are shown with red colour in accordance with their respective occupancy, and empty states are mentioned by shaded bars. Fig. 2 (b) displays the well known doubly magic nucleus ^{48}Ca with zero deformation where large shell gap around 4.9 MeV between the filled (red colour bar with occupancy 1) and empty states (shaded bar) shows conventional magicity, as expected. On the other side, when one moves from stable nucleus to neutron-rich side at ^{40}Mg, the shell gap between the states (filled and empty) almost disappears which leads to the breaking of shell closure at ^{40}Mg in concise with the Refs. [9, 10].

Our present investigations concludes that towards the proton-deficient side, ^{40}Mg is found to be deformed with prolate shape as predicted by both the parameters (DD-ME2 and DD-PCX). The N=28 shell closure disappears due to reduced gap between neutron single particle states which indicates the breaking of neutron magicity at ^{40}Mg.

The support provided by SERB (DST), Govt. of India under CRG/2019/001851 and WOS-A scheme is acknowledged.

References

[1] H. Iwasaki *et al.*, Phys. Lett. B **481** (2000) 7.
[2] S. Watanabe *et al.*, Phys. Rev. C **89** (2014) 044610.
[3] G. Saxena *et al.*, IJMPE **26** (2017) 1750072.
[4] G. Saxena *et al.*, Chin. J. Phys. **55** (2017) 1149.
[5] R. Sharma *et al.*, IJMPE (2021) https://doi.org/10.1142/S0218301321500701.
[6] R. Taniuchi *et al.*, Nature **569** (2019) 53.
[7] G. A. Lalazissis *et al.*, Phys. Rev. C **71** (2005) 024312.
[8] E. Yüksel *et al.* Phys. Rev. C **99** (2019) 034318.
[9] A. V. Afanasjev, *et al.*, Phys. Rev C **91** (2015) 014324.
[10] G. Saxena *et al.*, J Phys G: Nucl Part Phys, (2021) https://doi.org/10.1088/1361-6471/ac288b.