Magic numbers in neutron-rich nuclei using relativistic mean field model

M. S. Mehta[1],* S. K. Patra[2], and Raj K. Gupta[3]
[1]*Department of Applied Sciences, RBCEBTW,*
Mohali Campus, Mohali - 140 104, INDIA
[2]*Institute of Physics, Sachivalaya Marg, Bhubaneswar - 751 005, INDIA and*
[3]*Department of Physics, Panjab University, Chandigarh - 160 014, INDIA*

The studies of nuclei far away from the $\beta-$stability line are at the forefront of the modern nuclear physics, both experimentally as well as theoretically. With the advancement in ion-beam facility, the exploration of the properties of nuclei towards drip-lines has become possible, in particular, in the light mass region. The nuclear structures are evolving from macroscopic and microscopic models, and the experimental observations are made on nuclei close to the drip-lines.

The change in the spacing of the single particle levels, in the region away from stability-line, gives rise to shell gaps different from those observed for the stability-line. The sequence of the most fundamental quantity, the 'magic number', governing the structure of nuclei is changed in drip-line regions. Some of the traditional magic numbers loose their magicity in neutron-rich regions, and some other proton- or neutron-numbers emerge as magic numbers. The disappearence of the magic numbers N = 8 and 20 in the light nuclei, and/or appearence of the new magic numbers N = 16 and 32 in drip-line nuclei have been reported recentlty and can be found in Refs. [1–3]. It is interesting to extend this study to heavier mass regions of the nuclear landscape for investigating whether such structural changes occur there also. One case of particular interest is the magicity at proton/ neutron number N = Z = 28 and N = 32 and 40 near the neutron drip-line in Ca and Ni-isotopes, which has been a center of discussion for sometime now (see Ref. [4], and the refernces therein). These neutron magic numbers can be accounted for by the tensor force and the central part of one pion exchange potential (OPEP). The shell gap at Z = 28 is caused by the spin-orbit interaction and can easily be influenced by slight change of the potential due to unbalanced neutron and proton numbers. The shell gap at Z = 28 is predicted to be narrowed down by the tensor interaction between protons and neutrons [5]. Since the tensor interaction is strongly attractive between $\pi f_{5/2}$ and $\nu g_{9/2}$, and strongly repulsive between $\pi f_{7/2}$ and $\nu g_{9/2}$, the energy gap between $\pi f_{5/2}$ and $\pi f_{7/2}$ is reduced.

In the present calculations, we use the axially-deformed relativistic mean field (RMF) theory with NL3 parameter set. The pairing interaction is taken care within the BCS scheme, with gap parameters as in Ref. [6]. The results of calculations for two-neutron separation energies for $^{52-80}$Ni and $^{40-76}$Ca, and the neutron single particle energy levels for ^{60,68,78}Ni nuclei are, respectively, shown in Figs. 1 and 2. In Fig. 1, a sudden fall in the separation energy at N = 28 and 40 can be seen for the isotopes of both Ca and Ni, which indicate a better stability of nuclei at these numbers. In case of Ni-isotopes a sharp decrease in the separation energy at N = 50 is also obtained, which means that the magicity at N = 50 is also indicated in our RMF calculations. Fig. 2, showing a plot of single particle energy levels for ^{60,68,78}Ni, gives further insight of the magicity. Considerably large shell gaps ($\approx$ 6 MeV), both at N = 28 and 40 in ^{68}Ni nucleus appear. Note that this nucleus has been suggested to be a doubly magic nucleus experimentally [7]. Similarly, in ^{78}Ni nucleus,

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*Electronic address: `mehta_iop@yahoo.co.uk`

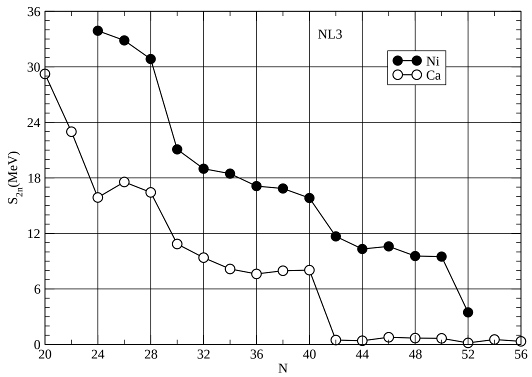

FIG. 1: The two neutron separation energy for $^{52-80}$Ni and $^{40-76}$Ca nuclei, using NL3 parameter set.

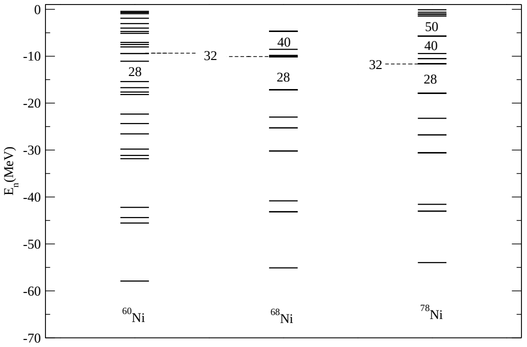

FIG. 2: The neutron single particle energy levels for ^{60,68,78}Ni isotopes.

the large shell gaps at N = 28, 40 and 50 are obtained. This shows that the magicity at N = 28 is perhaps not diminished, and the gap at N = 50 is nearly ∼4.0 MeV. The gaps in the single particle levels at these numbers are also consistent with the results of separation energy in Fig. 1. Although, a small gap at N = 32 in ^{60,78}Ni nuclei apppears but vanishes in ^{68}Ni, as is clear from Fig. 2. It may be reminded that ^{60}Ni is deformed in the ground state and ^{78}Ni is spherical, but the shell gaps are comparable.

Concluding, the RMF study with NL3 parameter set re-establishes the magicity at N=28, 40 and 50.

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