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Two Neutron Separation in Neutron-Rich Exotic Nuclei Near Drip Line

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INTRODUCTION

The number of neutrons in a neutron-rich nuclei out numbered the number of proton. The excess of neutron in neutron-rich nuclei invoked many exotic phenomena like neutron skin, nuclear halo, two neutron separation energy (S_{2n}) etc. The S_{2n} energy is the amount of energy required to pull out/separate two neutrons from a neutron rich nucleus. The energy required to remove one or two fermions from a strongly interacting system of fermions is directly related to the stability of the nuclear system. The S_{2n} energy is also related to the pairing energy of nuclei. As the pairing energy affects the binding energy of nuclei, two neutron separation energies should be different for both even-even and odd-odd nuclei. The extended shell gaps in the single-particle energy levels is identified as magic numbers in nuclei. Information about major shell closures i.e. the occurrence of magic numbers can be directly obtained from the evolution of the two neutron separation energy as a function of neutron number. The neutron skin thickness which is the measure of the difference between neutron and proton radii and its exact measurements can explain many aspects of nuclei such as density dependence of symmetry energy, slope parameter (L), isovector part of the nuclear interaction [1] etc. The exact measurements of neutron skin thickness are also important to study equation of state (EoS) of matter at very high densities.

THEORETICAL FORMALISM

The total energy of the system containing nucleons interacting with $\sigma-$, $\omega-$ and $\rho-$meson fields is given by

$$E_{total} = E_{part} + E_{\sigma} + E_{\omega} + E_{\rho} + E_{c} + E_{pair} + E_{c.m.}, \qquad (1)$$

here E_{part} is the sum of the single particle energies of the nucleons and E_{σ}, E_{ω}, E_{ρ}, E_{c}, E_{pair}, E_{cm} are the contributions of the meson fields, the Coulomb field, pairing energy and the center-of-mass energy, respectively. The starting point of RMF theory is the the fundamental Lagrangian density containing nucleons interacting with $\sigma-$, $\omega-$ and $\rho-$meson fields. The photon field A_{μ} is is incorporated to deal with the Coulomb interaction of protons. The Relativistic Mean Field Lagrangian density for a system of nucleons can be written as [2, 3, 4, 5, 6]

$$\begin{aligned}\mathcal{L} = {} & \bar{\psi_i}\{i\gamma^{\mu}\partial_{\mu} - M\}\psi_i + \frac{1}{2}\partial^{\mu}\sigma\partial_{\mu}\sigma - \frac{1}{2}m_{\sigma}^{2}\sigma^{2} - \frac{1}{3}g_{2}\sigma^{3} \\ & - \frac{1}{4}g_{3}\sigma^{4} - g_{s}\bar{\psi_i}\psi_i\sigma - \frac{1}{4}\Omega^{\mu\nu}\Omega_{\mu\nu} + \frac{1}{2}m_{w}^{2}V^{\mu}V_{\mu} \\ & - g_{w}\bar{\psi_i}\gamma^{\mu}\psi_i V_{\mu} - \frac{1}{4}\vec{B}^{\mu\nu}\vec{B}_{\mu\nu} + \frac{1}{2}m_{\rho}^{2}\vec{R}^{\mu}\vec{R}_{\mu} - \frac{1}{4}F^{\mu\nu}F_{\mu\nu} \\ & - g_{\rho}\bar{\psi_i}\gamma^{\mu}\vec{\tau}\psi_i\vec{R^{\mu}} - e\bar{\psi_i}\gamma^{\mu}\frac{(1-\tau_{3i})}{2}\psi_i A_{\mu}. \qquad (2)\end{aligned}$$

where M, m_{σ}, m_{ω} and m_{ρ} are the masses for nucleons, σ-, ω- and ρ-mesons and ψ is its Dirac spinor. The two-neutron separation energy is estimated using the following relation

$$S_{2n}(N,Z) = BE(N,Z) - BE(N-2,Z). \qquad (3)$$

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RESULTS and DISCUSSION

We performed this study using self-consistent axially deformed relativistic mean field model with effective NL3 parameters set. In figure 1, the variation of S_{2n} energy with neutron number is presented for odd-odd neutron-rich nuclei from C to Zr isotopes. As it is evident from figure 1, that the S_{2n} energy decreases smoothly with increasing neutron numbers indicating that as the number of neutron increases, the stability of the nuclei decreases. But we also observe abrupt fall in S_{2n} at N = 20, 40, 50, 70 and 82 in figures 1 which indicate that the isotopes are more stable at these particular nucleon number. The kinks at N = 20, 40, 50, 70 and 82 in figures 1 corresponds to the magic numbers in these isotopes. However, we noticed that there is no abrupt change in S_{2n} at N=28. Therefore, the magic number N=28 is no longer seen and disappear in all isotopes.

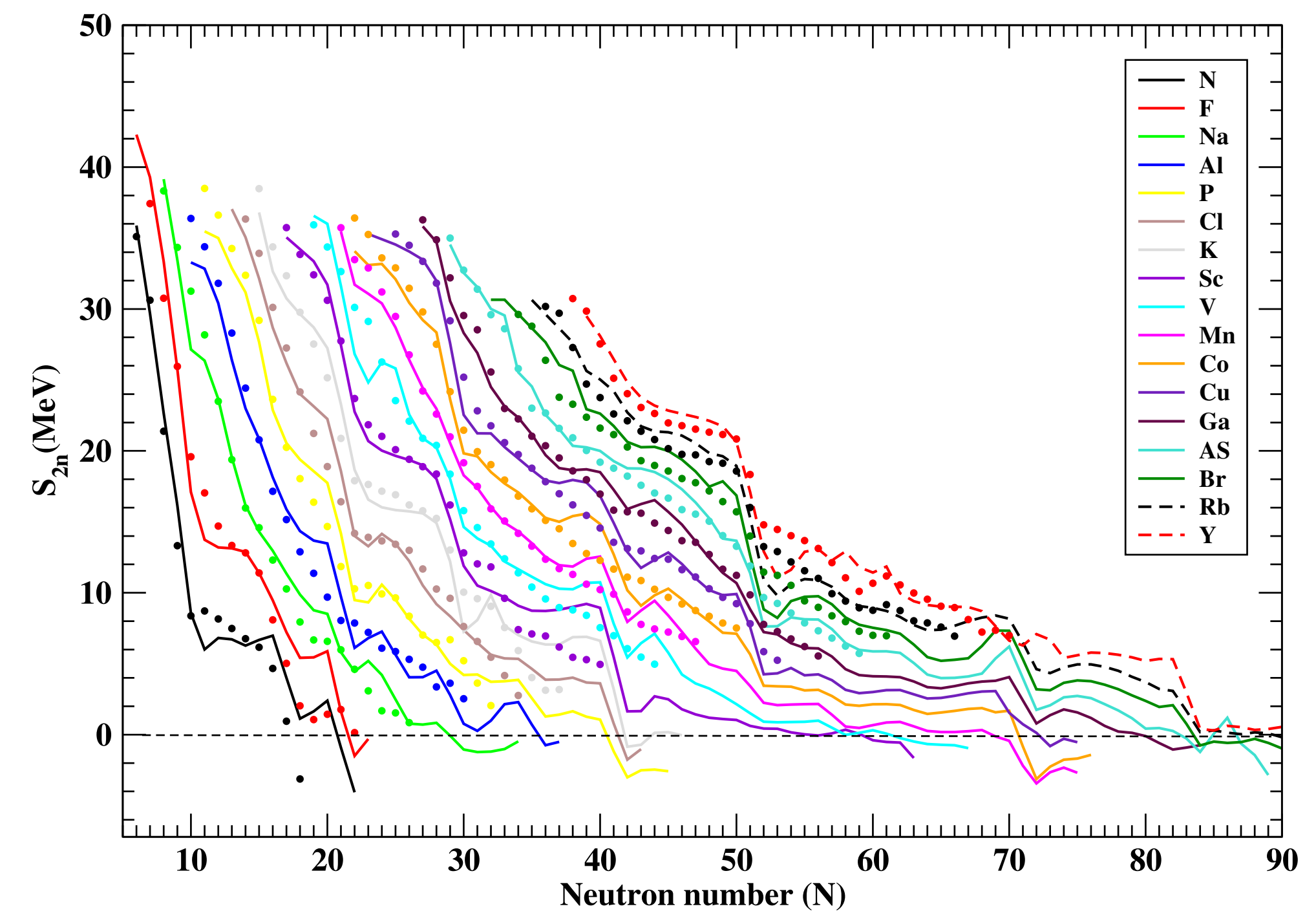

Figure 1: Two neutron-separation energy (S_{2n}) for the isotopic chain for odd-Z isotopes from C to Zr. Experimental data are shown by filled circles. The figure presented here is as same as in Ref. [7].

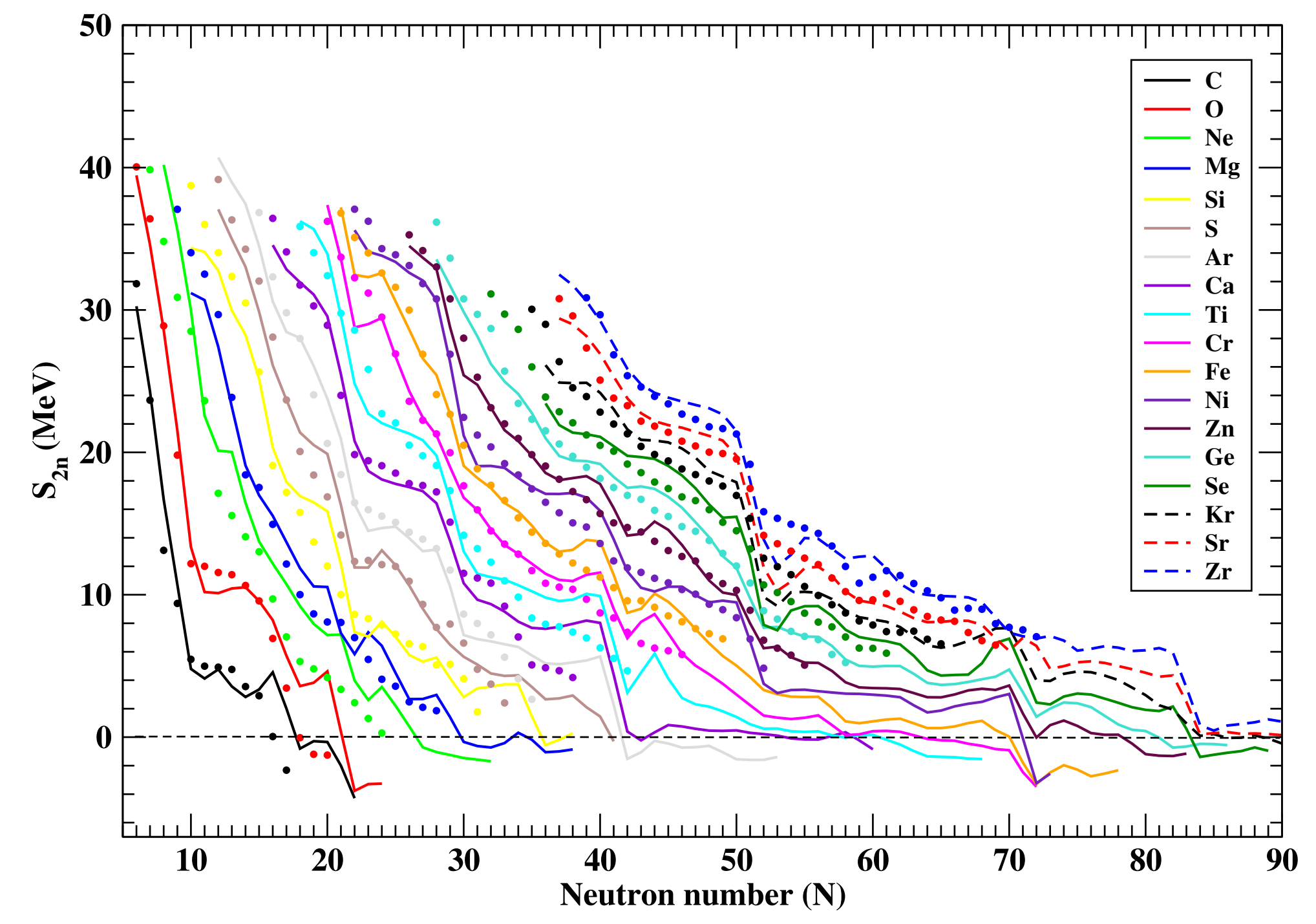

Figure 2: Two neutron-separation energy (S_{2n}) for the isotopic chain for even-even isotopes from C to Zr. Figure is same as in Ref. [7]

Figure 2, shows the variation of S_{2n} energy with neutron number but for even-even isotopes from C to Zr. In even-even nuclei we also observed the abrupt fall in S_{2n} which suggests magic number are also found in even-even nuclei. Similar are the results for the odd-Z nuclei isotopic chain but we noticed that in odd-Z nuclei the value of S_{2n} energy is less in comparison to even-Z nuclei. Thus, we can say that odd-Z nuclei are less stable in comperision of even-Z nuclei. In figure 3, neutron skin thickness as a function of neutron number N from β stable to drip line region for both even-even and odd-odd nuclei is presented. We noticed that Skin thickness increases continuously with increase in number of neutrons for both types of isotopes. Due to redistribution and increase in the number of nucleons, the neutron skin increases for O, Ni, Kr, Rb, Sr, Y, and Zr in comparison to other isotopes and subsequent stable nucleus formation. We also noticed that Ni with N $>$ 50 and Kr, Rb, Sr, Y, Zr isotopes with N $>$ 82 show a sharp increase in skin thickness.

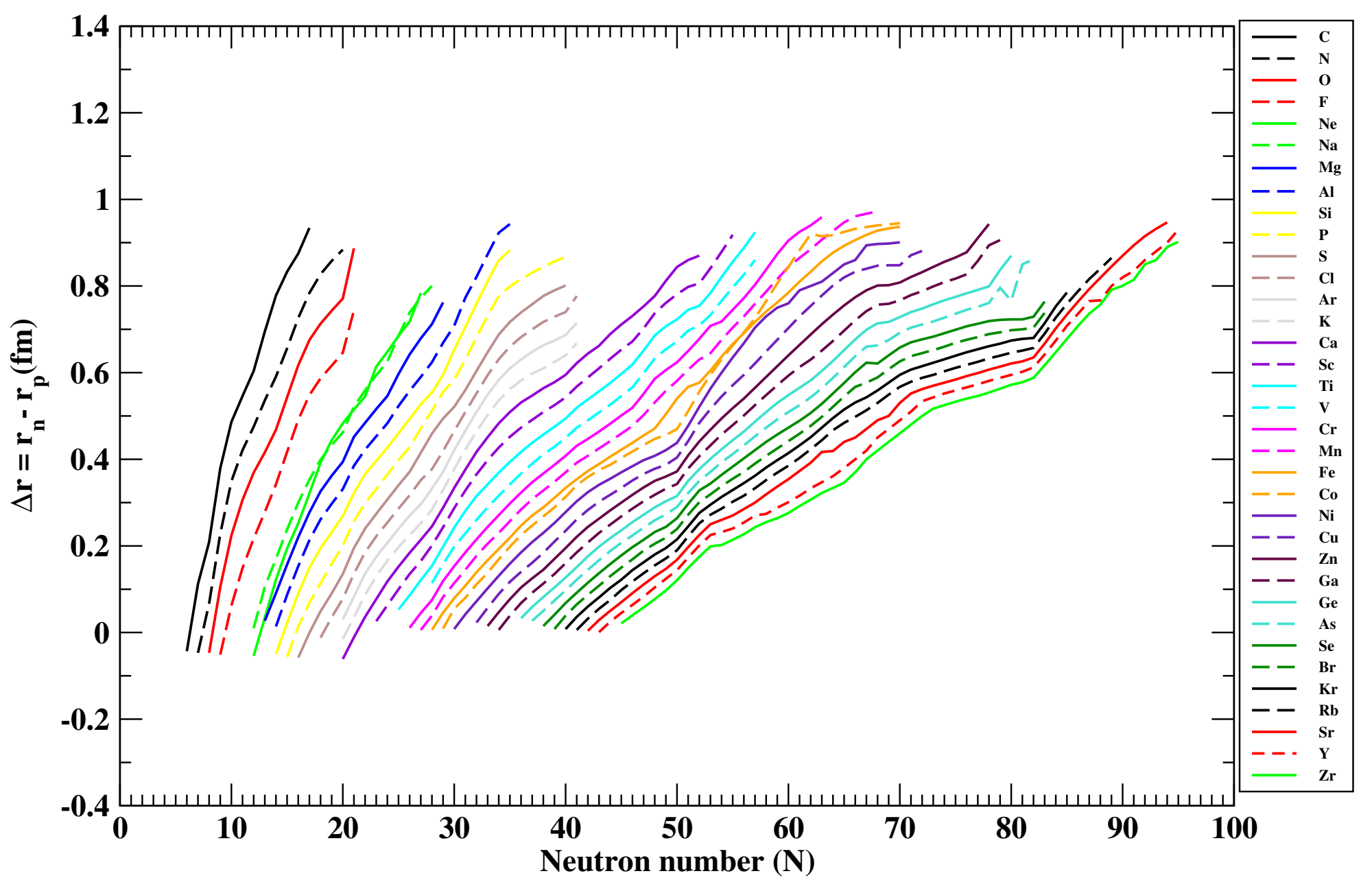

Figure 3: Neutron skin-thickness from β stable to drip line region is given as a function of neutron number from C to Zr isotopes. Even-even isotopes are represented by solid line whereas dashed line is used for showing the odd-odd isotopes. Figure is taken from Ref. [7]

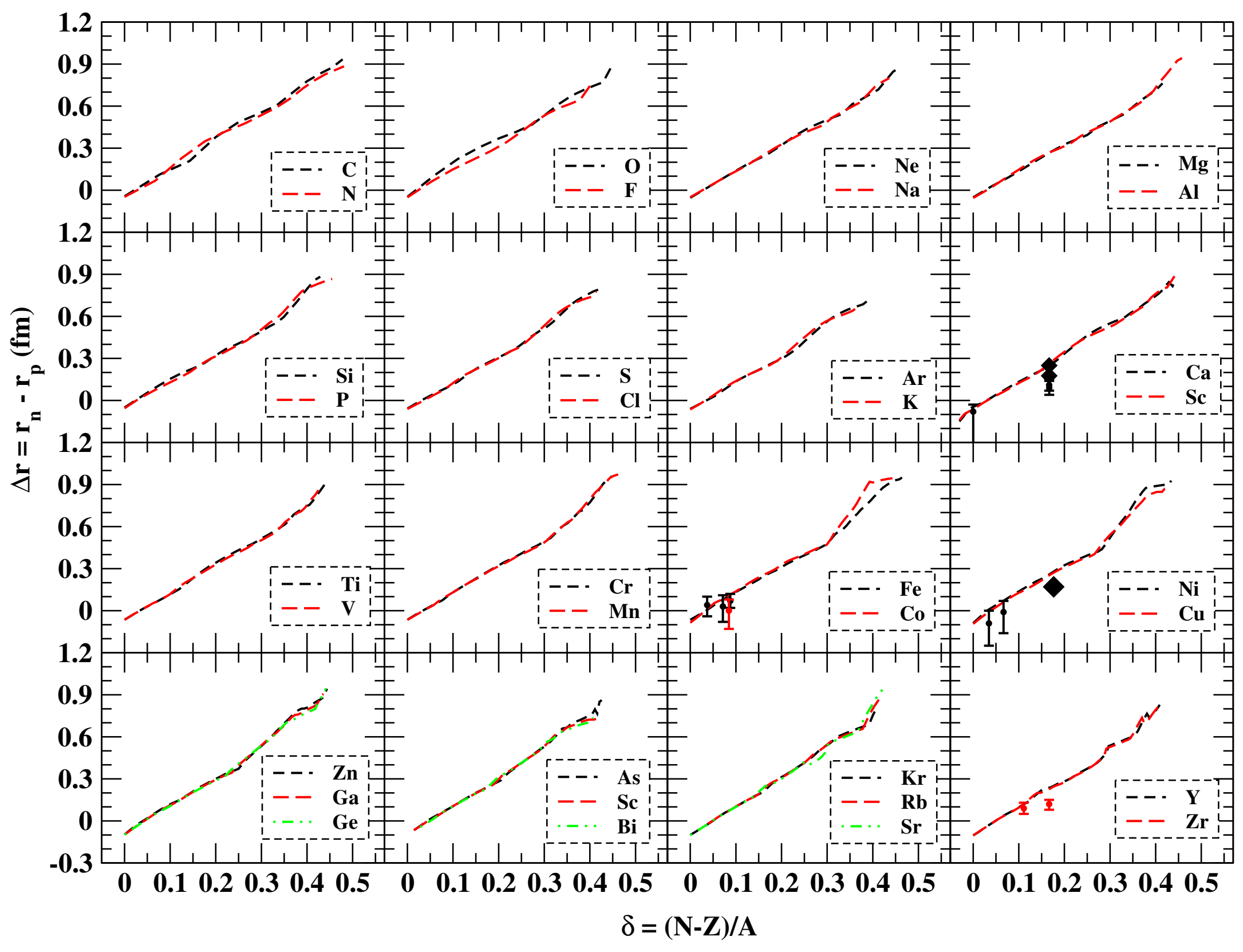

Figure 4: Figure shows the skin thickness as a function of asymmetry energy parameter (δ=N-Z/N+Z) for the isotopes from C to Z. Experimental data are represented by filled circles. Figure taken from Ref. [7]

Moreover, to understand the neutron skin thickness in neutron-rich nuclei interplay of neutron skin thickness with asymmetry parameter (δ=N-Z/N+Z) is also studied and presented in 3 The graph 3 shows the correlation of skin thickness with asymmetry parameter. We noticed a linear dependence of neutron-skin thickness with the relative neutron excess in a nuclei. The calculated results are in well agreement with available experimental data [8, 9].

CONCLUSIONS

- The study suggests that the self-consistent axially deformed relativistic mean field model with effective NL3 is capable to explain the properties of neutron-rich nuclei such as S_{2n} and neutron skin thickness for the considered isotopic chain from C to Zr.
- Evolution of S_{2n} with neutron number for the isotopic nuclei from C to Zr clearly suggests the shell closures at N = 20, 40, 50, 70 and 82.
- From the curves in which variation of S_{2n} with neutron number for odd-odd and for even-even nuclei are presented, one can predicts that even-even nuclei are more stable than odd-odd nuclei.
- Neutron skin thickness and its interplay with neutron number and asymmetry energy parameter (δ=N-Z/N+Z) are studied which provide important information about the structure of the nuclei under consideration.

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