Radii and Density Distribution of N = 28 Isotones

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In the present investigations we have employed relativistic mean-field plus BCS (RMF + BCS) approach [1–3] to study the variation of root mean square radii and the density profiles for the entire chain of even even N = 28 isotones upto drip-lines. Root mean square radii for the nuclei of the N = 28 isotonic chain obtained from our deformed RMF+BCS calculations [1] and spherical RMF+BCS calculations [2, 3] with TMA force parameters have been displayed in Fig. 1 along with the available experimental data [4] for the purpose of comparison. It is observed from Fig. 1 that with increasing number of protons the rms radius for the proton distribution r_p increases gradually to have maximum value for the heaviest bound nucleus $^{58}_{30}Zn_{28}$ for N=28 isotonic chain. A comparison shows that the deformed RMF results for the nuclei with Z = 12, 14 and 16 are not similar to those obtained from the spherical RMF calculations as the nuclei with Z = 12, 14 and 16 are appreciably deformed. Also, since the rest of the nuclei

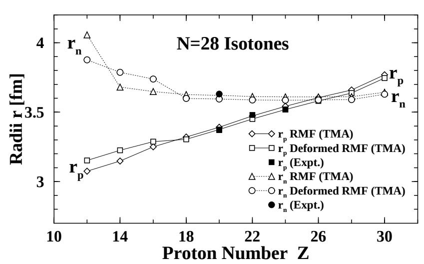

FIG. 1: The rms radii of neutron and proton distributions, r_n and r_p, respectively, for the nuclei constituting N = 28 isotonic chain.

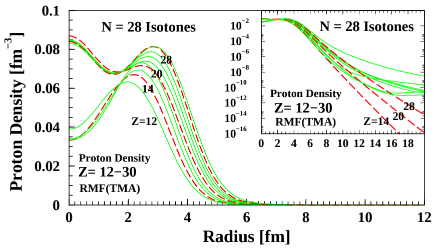

FIG. 2: The variation in the radial dependence of the proton density for the nuclei with increasing proton number Z in the isotonic chain with N = 28. The inset shows the results on a logarithmic scale up to rather large radial distances. Long dashed lines have been used to indicate the density of isotones which exhibit proton shell closure.

in the N = 28 isotonic chain have negligible deformation the spherical and deformed RMF calculations yield results for the radii r_p and r_n, respectively, close to each other as is evident from Fig. 1. The radius of the neutron distribution r_n is expected to remain almost unchanged. The detailed features of results of radii for the neutron and proton distributions can also be demonstrated in terms of radial dependence of the neutron and proton densities of these nuclei employing the spherical RMF+BCS calculations using TMA force parameters. It may be stated that here we are considering only the spherical RMF+BCS calculations in order to have the convenience of using the spherical description which, in contrast to the deformed RMF+BCS approach, enables to plot the densities simply only as a function of radial distance.

As is seen in the Fig. 2 the main part of the proton distributions are observed to be confined to smaller distances (4 to 5 fm) with increasing proton number Z. Thus we see that in

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the interior as well as at outer distances the proton density values are larger for the proton rich N =28 isotones and gradually become smaller with decreasing proton number Z. Due to this feature the proton radii are found to monotonically increase, albeit in a small measure, with increasing proton number Z as has been illustrated earlier in Fig. 1. It may be remarked that since for the entire isotonic chain under consideration the neutron number is constant, for rather small proton number Z the isovector component of the nuclear interaction is attractive between the protons and repulsive for the neutrons [5]. Thus for the isotones with large difference in neutron and proton number the Coulomb repulsion is partly compensated by the isovector part of the nuclear attraction. Consequently, for nuclei in the isotonic chain N = 28 with much smaller values of proton number Z, the proton density is more confined as compared to the case of nuclei with proton number close to N = 28 as is evident from Fig. 2. In contrast, since the isovector part of nuclear force between the neutrons is repulsive, the neutron densities for the nuclei with small Z values in the isotonic chain N = 28 are found to be extended to outer region as compared to those nuclei which have proton number close to N = 28. This effect is evidently seen in Fig. 3 which depicts the variation in the radial dependence of the neutron density for the nuclei with increasing proton number. It is also found that the neutron density is widely spread over large distances and forms an appreciable neutron skin in the case of neutron rich nucleus such as ^{40}Mg in the isotonic chain with N = 28. The depletion of the central proton density in Fig. 2 for the light nuclei with smaller proton number (Z = 12, 14 and 16) in the isotonic chain can be understood in terms of single particle energy levels. Because the single particle 1s-, 2s etc. orbitals in nuclei do not have any centrifugal barrier, in a nucleus with unoccupied s-state the central density becomes depleted as compared to the nucleus wherein this state is fully occupied. Recently Grasso et al. [6] have made a detailed analysis employing the shell model and mean-field methods, both relativistic as well as nonrelativistic, for the depletion of central proton density (also called "bubble" structure formation) in ^{34}Si and ^{22}O. We follow here this argument to make a qualitative analysis of the proton density profile shown in Fig. 2 for the isotonic chain with N = 28. Details show that the proton single particle $2s_{1/2}$ state remains almost unoccupied for nuclei up to Z = 18. Therefore, the proton central density for nuclei with Z = 12, 14, 16 and 18 remains depleted. With addition of two more protons, the proton $2s_{1/2}$ state gets filled in and for isotones with Z beyond 18 the proton central density is no more depleted as is seen in Fig. 2.

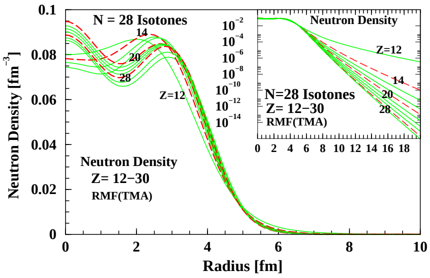

FIG. 3: same as for Fig. 2 but for neutron density.

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References

[1] L. S. Geng et. al, Prog. Theor. Phys. **113** (2005) 785.
[2] H. L. Yadav et. al, Int. Jour. Mod. Phys. **E 13** (2004) 647 and reference therin.
[3] G. Saxena et.al, Modern Physics Letters **A23**, (2008) 2589.
[4] H. de Vries et. al, At. Data Nucl. Data Tables **36** (1987) 495.
[5] J. Dobaczewski et. al, Eur. Phys. J. **A 15** (2002) 21 and reference therein.
[6] M. Grasso et. al, Phys. Rev. **C 64** (2001) 064321, Phys. Rev. **C79** (2009) 034318.