RMF+BCS approach for "Bubble Structures"

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Introduction

"Bubble structure" i.e. depletion in central density has been discussed recently in superheavy and hyperheavy nuclei [1, 2]. In the nucleus, s-orbitals (l=0) have radial distributions peaked in the interior of the nucleus due to zero centrifugal barrier. Their wave function extend further into the surface depending on the number of nodes. Whereas orbitals with non-zero angular momenta are suppressed in the nuclear interior and do not contribute to the central density. Therefore, any vacancy of s-orbitals is expected to produce a depletion of the central density. Recently formation of bubble structure is discussed for ^{46}Ar in Ref. [3], for ^{34}Si and ^{22}O in Ref. [4]. We have applied Relativistic Mean Field plus BCS (RMF+BCS) approach [5–7] to study bubble structures in the above said nuclei which are of current interest.

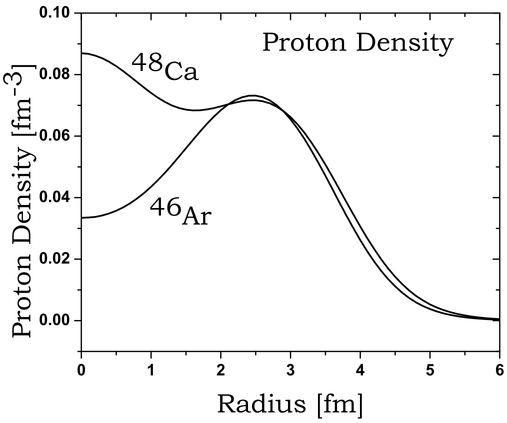

FIG. 1: Proton density of ^{46}Ar and ^{48}Ca obtained using RMF+BCS approach using TMA force parameter.

Theoretical Formulation and Model

$$
\begin{aligned}
\mathcal{L} \;=\; & \bar{\psi}[\imath\gamma^{\mu}\partial_{\mu} - M]\psi + \frac{1}{2}\,\partial_{\mu}\sigma\partial^{\mu}\sigma - \frac{1}{2}m_{\sigma}^{2}\sigma^{2} \\
& -\frac{1}{3}g_{2}\sigma^{3} - \frac{1}{4}g_{3}\sigma^{4} - g_{\sigma}\bar{\psi}\sigma\psi - \frac{1}{4}H_{\mu\nu}H^{\mu\nu} \\
& +\frac{1}{2}m_{\omega}^{2}\omega_{\mu}\omega^{\mu} + \frac{1}{4}c_{3}(\omega_{\mu}\omega^{\mu})^{2} - g_{\omega}\bar{\psi}\gamma^{\mu}\psi\omega_{\mu} \\
& -\frac{1}{4}G_{\mu\nu}^{a}G^{a\mu\nu} + \frac{1}{2}m_{\rho}^{2}\rho_{\mu}^{a}\rho^{a\mu} - g_{\rho}\bar{\psi}\gamma_{\mu}\tau^{a}\psi\rho^{\mu a} \\
& -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - e\bar{\psi}\gamma_{\mu}\frac{(1-\tau_{3})}{2}A^{\mu}\psi
\end{aligned}
$$

Our RMF calculations have been carried out using the model Lagrangian density with nonlinear terms both for the σ and ω mesons along with the TMA parametrization as described in detail in Refs. [5, 8].

where the field tensors H, G and F for the vector fields are defined by

$$
\begin{aligned}
H_{\mu\nu} &= \partial_{\mu}\omega_{\nu} - \partial_{\nu}\omega_{\mu} \\
G_{\mu\nu}^{a} &= \partial_{\mu}\rho_{\nu}^{a} - \partial_{\nu}\rho_{\mu}^{a} - 2g_{\rho}\,\epsilon^{abc}\rho_{\mu}^{b}\rho_{\nu}^{c} \\
F_{\mu\nu} &= \partial_{\mu}A_{\nu} - \partial_{\nu}A_{\mu}\ ,
\end{aligned}
$$

and other symbols have their usual meaning.

Results and Discussions

Bubble candidates are nuclei where the s state is depopulated. In the proton bubble case it corresponds to Z = 18(Ar) and Z = 20(Ca). In ^{46}Ar proton $2s_{1/2}$ state is depopulated whereas in ^{48}Ca it is completely filled. Therefore depletion in proton density is seen

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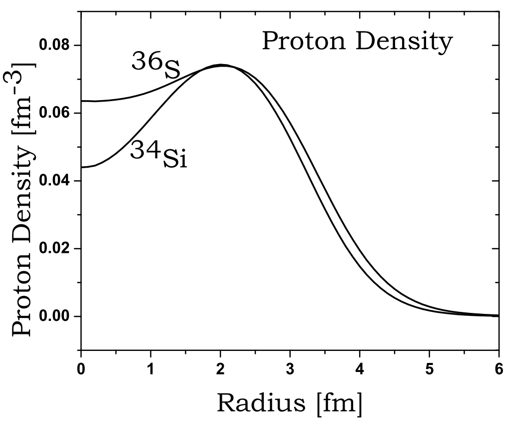

FIG. 2: Proton density of ^{34}Si and ^{36}S obtained using RMF+BCS approach using TMA force parameter.

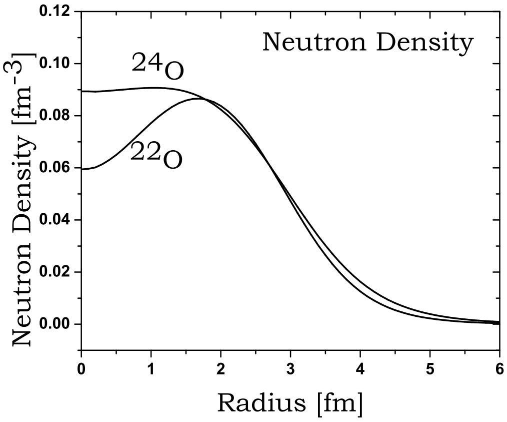

FIG. 3: Neutron density of ^{22}O and ^{24}O obtained using RMF+BCS approach using TMA force parameter.

when compared in Fig 1, where proton densities of both ^{46}Ar and ^{48}Ca are shown. It is evident from figure that for radius more than r = 2 fm densities are almost same and near center ($0 < r < 2$ fm) bubble structure can be seen for ^{46}Ar nucleus.

In some cases bubble structure occurs due to an inversion between the s state and the one usually located above. It happens for the case of N = 20 isotones where $2s_{1/2}$ state filled before $1d_{3/2}$ state thereby forming two subshell closures at Z = 14 and Z = 16. It has been illustrated in Fig. 2 in the formation of proton bubble structure in ^{34}Si isotopes where proton $2s_{1/2}$ state is unfilled and situated around 7 Mev above the filled $1d_{5/2}$ state. This proton $2s_{1/2}$ state is filled in ^{36}S of this isotonic chain and resulting proton bubble in ^{34}Si as shown in Fig. 2.

For neutron side, this phenomenon is observed in N = 14 and N = 16 for ^{22}O and ^{24}O respectively. In the case of ^{24}O the neutron single-particle state $2s_{1/2}$ is fully occupied. The depletion of the central density in ^{22}O relative to ^{24}O is clearly visible in Fig. 3.

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