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Nuclear Bubble in Sn Isotope Within Modified Relativistic Mean Field

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Abstract. Nuclear bubble is one of the interesting phenomena in nuclei. Nuclear bubble is characterized by existence of depletion at the center of nuclei [1, 2]. In this study, we investigated the nuclear bubble phenomena on Sn isotopes by assuming the corresponding nuclei are spherical. We used Modified Relativistic Mean Field model [3] to describe the interaction among nucleons in nuclei. It is found that the corresponding depletion near the center of each nucleus density in Sn isotope is insensitive to the nonlinear isovector parameter variation. In this work, we also study the effects of tensor and electromagnetic exchange term of the corresponding model on nuclear bubble phenomena on Sn isotopes.

Keywords: nuclear bubble, Sn isotope, relativistic mean field model

INTRODUCTION

The nuclear bubble is characterized by depletion at its central density [1]. To find out the nuclear bubble requires an investigation of the nuclear structure, not only to measure the reliability of effective nuclear interactions but also to reproduce the binding energy, the radius of charge and the observed density distribution. The atomic binding energy is the most accurate data specified in nuclear structure, most information of nuclear interaction embedded in it [4, 5]. The effect of tensor coupling, isoscalar and electromagnetic exchange is studied through the theory of Modified Relativistic Mean Field (MRMF). It was found that the tensor coupling, the isoscalar and electromagnetic interchanges had a significant effect on the nature of nuclear matter, energy binding, single particle energy spectrum, density distribution and core skin thickness [3]. Electromagnetic exchange energy contribution can be obtained using formulas with a relative deviation of less than 1 % for semi-magic isotopes Ca, Ni, Sn and Pb. The energy difference from the lowest state corresponds to two single particle orbitals on Z = 50 proton shells. The nuclear structure in the mass region $A \approx 100$ to $A \approx 130$ offers a number of interesting features, in particular due to the shell enclosure on N or Z equal to 50 and 82. Sn isotope provides ideal conditions to gain insight into the phenomenon of change in nuclear structure and related characteristics, in areas of neutron deficiency (N = Z = 50) double magic nuclei to a neutron rich region. Sn isotope has the largest stable isotope chain (Sn^{100} - Sn^{136}) and structural evolution in Sn isotope has been studied deeply at N = 82 to Sn^{136}, theory as good as experiment. The approaching Sn^{132} nuclear structure is very important, on the one hand offering an opportunity to study the effects in couples and deformations due to skin effects such as from Sn^{100} to Sn^{132} [2].

FORMALISM

In the past, the RMF models has been successfully employed to study finite nuclei and nuclear matter properties [6]. The Lagrangian density of the system is [3]

$$\mathcal{L} = \mathcal{L}^{free}_{nucleon} + \mathcal{L}^{free}_{meson} + \mathcal{L}^{linear}_{int} + \mathcal{L}^{nonlin}_{int} + \mathcal{L}^{\tau} + \mathcal{L}^{C}_{exc}, \tag{1}$$

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where $\mathcal{L}^{free}_{nucleon}$, $\mathcal{L}^{free}_{meson}$, $\mathcal{L}^{linear}_{int}$, $\mathcal{L}^{nonlin}_{int}$, $\mathcal{L}^{\tau}$ and $\mathcal{L}^{C}_{exc}$ are Lagrangian density for nucleon, meson, linear interaction, nonlinear interaction, tensor coupling and coulomb exchange. The free-nucleon part lagrangian density in Equation 1 can be expressed as

$$\mathcal{L}^{free}_{nucleon} = \sum_{j=1}^{A} \bar{\psi}_j \left[i\gamma^{\mu}\partial_{\mu} - M \right] \psi_j. \tag{2}$$

with ψ and M are field and mass of the nucleons, respectively. The Lagrangian density for meson in Equation 1 is

$$\begin{aligned} \mathcal{L}^{free}_{meson} &= \frac{1}{2}\left(\partial_{\mu}\phi\partial^{\mu}\phi - m_{\sigma}^2\phi^2\right) - \frac{1}{2}\left(\frac{1}{2}V_{\mu\nu} - m_{\sigma}^2 V_{\mu}V^{\mu}\right) - \frac{1}{2}\left(\frac{1}{2}R_{\mu\nu}R^{\mu\nu} - m_{\rho}^2 V_{\mu}V^{\mu}\right) \\ &+ \frac{1}{2}\left(\partial_{\mu}\bar{d}\partial^{\mu}\bar{d} - m_{\delta}^2\bar{d}^2\right) - \frac{1}{2}\partial^{\nu}A^{\mu}\partial_{\nu}A_{\mu}, \end{aligned} \tag{3}$$

here A_{μ} is an electromagnetic field, while m_{σ}, m_{ω} and m_{ρ} are σ, ω and ρ meson masses. The Lagrangian density for interaction is

$$\mathcal{L}^{lin}_{int} = \Sigma^{A}_{j=1}\bar{\psi}_j \left(g_{\sigma}\phi - g_{omega}\gamma^{\mu}V_{\mu} - \frac{1}{2}g_{\rho}\gamma^{\mu}\tau R_{\mu} + g_{\delta}\bar{d} - eA^{\mu}\frac{1+\tau_o}{2}\gamma_{\mu} \right)\psi_j, \tag{4}$$

where g_{σ}, g_{ω}, g_{ρ} and e are σ, ω, ρ and photon coupling constants. The Lagrangian density for non-linear interaction is

$$\mathcal{L}^{nonlin}_{int} = -\frac{1}{3}b_2\psi 3 - \frac{1}{4}b_3\psi 4 + \frac{1}{4}c_3\left(V_{\mu}V^{\mu}\right)^2, \tag{5}$$

where b_2, b_3 and c_3 are standard RMF nonlinear parameters and Λ is the parameter of isoscalar-isovector coupling term. The Lagrangian density for tensor couplings is

$$\mathcal{L}_T = -\sum_{j=1}^{A}\left(\frac{f_{\omega}}{2M}\partial^{\nu}V^{\mu}\bar{\psi}_j i\gamma_{\mu}\gamma_{\nu}\psi_j + \frac{f_{\rho}}{4M}\partial^{\nu}R^{\mu}\bar{\psi}_j\tau i\gamma_{\mu}\gamma_{\nu}\psi_j \right), \tag{6}$$

and self interaction meson ρ and ω can be expressed as

$$\mathcal{L}_{\rho\omega} = g_{\omega}^2 g_{\rho}^2\Lambda(V_{\mu}V^{\mu})(\vec{R}_{\mu}.\vec{R}^{\mu}). \tag{7}$$

Note that f_{ω} and f_{ρ} are isoscalar and isovector tensor coupling constants, respectively. Similar to the one of SHF, we only use the relativistic local density approximation (RLDA) form for Coulomb-exchange energy density. The contribution takes following form

$$\mathcal{L}^{EM}_{EXC} = C^{EM}_{EXC}\left[\frac{3}{4}e^2\left(\frac{3}{\pi}\right)^{\frac{1}{3}}\right]\rho_p^{\frac{3}{4}}\left[1 - \frac{1}{3M^2}(3\pi^2)^{\frac{2}{3}}\rho_p^{\frac{2}{3}}\right]. \tag{8}$$

In this work, we investigate effect of coupling tensor, electromagnetic exchange and nonlinear isovector variation. The coupling constants of nonlinear isovector from Λ and electromagnetic exchange C^{exc} are not fitted in our case.

DENSITY DISTRIBUTION AND DEPLETION

Density distribution is needed to calibrate the effective neutron and proton interaction. Information from these densities can also give insight to the shape and the structural aspects. To have further qualitative view of the depletion of density near center, we have plotted depletion fraction which a measure of bubble nuclei viz-a-viz probability fraction for proton, neutron or nucleon. The depletion fraction can be defined as [1]

$$\mathcal{DF} = \frac{\rho_{max} - \rho_{cen}}{\rho_{max}} \tag{9}$$

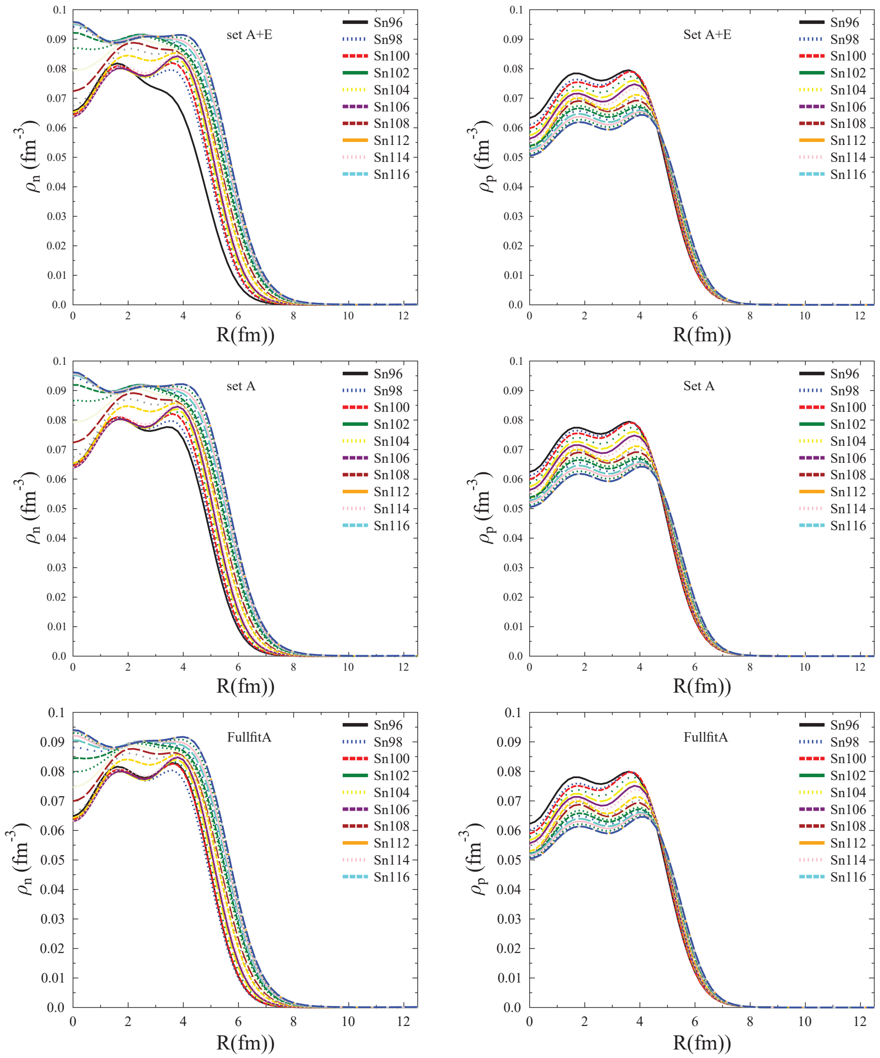
where ρ_{max} and ρ_{cen} represent the values of maximum density and central density of neutron, proton and total nucleons.

RESULTS AND DISCUSSION

We can observe the nuclear bubble phenomenon in Sn isotope predicted by each parameter set used from the nucleon densities distribution. Through the differences in nucleon densities distribution close to center in the corresponding plots. We can also analyze the neutron skin thickness predictions of each parameter set in the region close to the surface. Because basically the thickness of neutron skin is different between the neutron radius and the proton radius in Sn isotope.

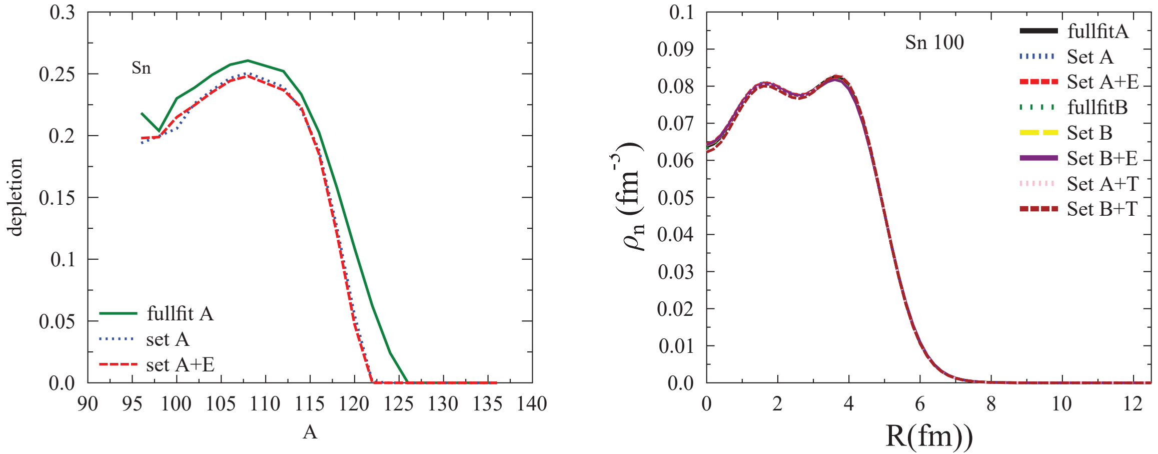
As shown in Fig. 1, in Sn isotope, for neutron densities case, we can observe a different change of density by varied neutron number in the region near the center of nuclei. While for proton densities case, this behaviour is not present. It means that nuclear bubble effect on neutron densities of Sn isotopes. There is a difference neutron densities move from Sn^{96} to Sn^{98},Sn^{98} to Sn^{100} in the region close to the surface of nucleus. This shows the thickness of neutron skin of each nucleus is different in Sn isotope.

From Fig. 2a it is clear that the depletion of neutron density begins to appear on the Sn with A > 110 isotope. This estimation based on the fact that the number of neutrons significantly increases compared to the number of protons



(a) (b)

FIGURE 1. (a) neutron density as a function of radius *r* in Sn isotope. (b) proton density as function of radius *r* in Sn isotope.



(a) (b)

FIGURE 2. (a) Neutron depletion as function of nucleon number A. (b) Comparison results. Depletion variation due to variation of nonlinear isovector and electromagnetic exchange parameters.

in the corresponding region. However, in the case of isotope Sn with A > 124, the depletion is not visible because the number of protons also starts to increase. Nonlinear isovector terms makes neutron skin thicker and impact on the greater the depletion of neutrons. Furthermore we also calculate impact tensor coupling, nonlinear isovector and electromagnetic exchange on Sn^{100}. Figure 2b shows there were no significant contribution of these three terms.

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