Halo or Skin in Zr-Isotopes

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Introduction

The information of properties of neutron-rich (in particular) nuclei in the region away from β-stability line is becoming more and more clear with the availability of more energetic radioactive beams of short-lived nuclei of the rare isotope. In the recent decades, the studies of nuclear structure has made a considerable progress by exploring new phenomena that opened up the new frontiers in the field. The density distribution of nucleons is an important observable of nucleus which gives information of a nucleus . The density distribution of nuclei towards the drip-line is quite different to the one near the β-stability line. A significant character in nuclei at the extreme is the existence of nuclear halos and skins [1]. This exotic property of nuclei in light mass region was first observed by I. Tanihata et al. [2], experimentally, in 1985 for ^{11}Li.

The definition of a halo nucleus is still being debated. The large value of N/Z ratio in unstable nuclei produces a large difference in Fermi energy of neutrons and protons, and thus, decoupling of neutron and proton distributions appears as halos and/ or skins. The halo structure in nuclei can appear when the system reaches the threshold and the role of long-range repulsive force on relative motion of particle becomes less. As a result the tail of wave function extends farther away from the region of nuclear interaction, thereby producing an unusual extended region of low nuclear density distribution. The other interesting features in nuclei close to neutron drip-line are, for example, the largely extended spatial density distribution, coupling of bound states to the continuum, the Borromean structure etc. In the past, several theoretical models in relativistic kinematics such as Hartree Bogoliubov with or without the Fock term, Relativistic Mean Field model with hartree approximation have been developed for a self-consistent description of spherical as well as deformed halo nuclei.

Very recently, the nuclear reaction cross-sections of ^{19,20,22}C [3] nuclei are measured and it is shown that ^{22}C nucleus has halo structure. This drip-line nucleus is reported to be two neutron halo nucleus. Also, ^{42,44}Mg nuclei which are close to neutron drip-line have been predicted as showing halo structure [4, 5]. The nuclei ^{11}Be, ^{19}C, ^{31}Ne are the examples of one-neutron halo [6, 7]. Usually, halo is the name given to the long extended low density tail in the nuclear matter distribution, which results in larger radius. On the other hand, the neutron skin is the significant difference in the values of matter radii for neutrons and protons. The neutron skin, qualitatively, describes an excess of neutrons at the nuclear surface. Recently, the skin thickness is calculated [8] for ^{208}Pb and its correlation with the slope of symmetry energy.

In the present work we employ axially deformed relativistic mean field model with NL3 parameterization to calculate the neutron and proton density distributions.

Formalism

The Relativistic Mean Field formalism is used here to investigate the decay properties of superheavy nuclei. The Lagrangian density as given by,

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$$
\begin{aligned}
\mathcal{L} &= \overline{\psi_i}\{i\gamma^{\mu}\partial_{\mu} - M\}\psi_i + \frac{1}{2}\partial^{\mu}\sigma\partial_{\mu}\sigma - \frac{1}{2}m_{\sigma}^2\sigma^2 \\
&- \frac{1}{3}g_2\sigma^3 - \frac{1}{4}g_3\sigma^4 - g_s\overline{\psi_i}\psi_i\sigma - \frac{1}{4}\Omega^{\mu\nu}\Omega_{\mu\nu} \\
&+ \frac{1}{2}m_w^2 V^{\mu}V_{\mu} + \frac{1}{4}c_3(V_{\mu}V^{\mu})^2 - g_w\overline{\psi}_i\gamma^{\mu}\psi_i V_{\mu} \\
&- \frac{1}{4}\vec{B}^{\mu\nu}.\vec{B}_{\mu\nu} + \frac{1}{2}m_{\rho}^2\vec{R}^{\mu}.\vec{R}_{\mu} - g_{\rho}\overline{\psi}_i\gamma^{\mu}\vec{\tau}\psi_i.\vec{R}^{\mu} \\
&- \frac{1}{4}F^{\mu\nu}F_{\mu\nu} - e\overline{\psi}_i\gamma^{\mu}\frac{(1-\tau_3)}{2}\psi_i A_{\mu}
\end{aligned}
$$

where ψ is Dirac spinor for nucleon and M is mass of nucleon. The quantities m_{σ}, m_{ω}, and m_{ρ} are the masses of σ, ω, and ρ. The nonlinear self interaction coupling of σ mesons is denoted by g_2 and g_3. In the present calculations, we employ NL3 parameterization for meson-baryon coupling.

Results and Discussion

The halo and/or skin in nuclei is a threshold effect that arises due to a very weak binding of the last one or two valence nucleons and hence get decoupled from the rest of nucleons in nucleus. The variation of neutron and proton densities as a function of distance from the nucleus gives the insight of the distribution of nucleons near the surface of nucleus. The tail part of density distribution is important as far as the skin and halo structure is concerned.

The baryon density is calculated by the relation given by,

$$
\rho_v(r) = \sum_{i=1}^{A} \psi_i^{\dagger}(r)\psi_i(r)
$$

The baryon density is the sum of squares of large and small components of Dirac spinors and is normalized to nucleon number.

In the present work, we calculate the neutron and proton density distributions for even-even Zr-isotopes ($^{130-140}$Zr) using axially deformed relativistic mean field model. The density distribution of neutron and proton is plotted in figure 1. From the figure it is clearly visible that the neutron density for all isotopes

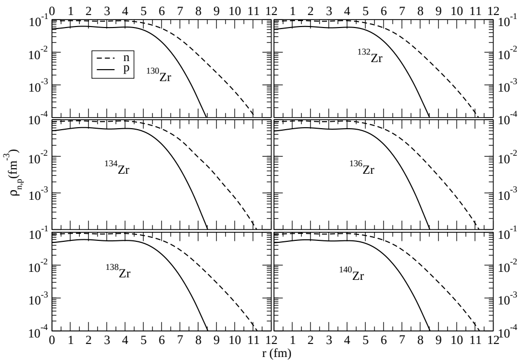

FIG. 1: The density distribution for even-even $^{130-140}$Zr nuclei using NL3 parameter set.

considered here has extended tail as compared to proton density. The extension in neutron density is ≥ 2.5 fm at the outer region of nuclei. Such a long tail indicates the halo (or near halo) nature of these nuclei. At the central region the neutron density is comparatively larger than the proton density, which shows Coulomb repulsion among protons. In the isotopic series $^{130-140}$Zr most of the nuclei are spherical or near spherical and oblate deformed.

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