Neutron and proton density distribution in Carbon isotopes

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Introduction

Carbon isotopes exhibit unique nuclear properties, such as the halo nucleus phenomenon observed in isotopes like ^{15}C,^{19}C and ^{22}C [1]and the Hoyle state in ^{12}C which plays a crucial role in stellar nucleosynthesis.[2] Additionally, ^{12}C is used as a standard reference with its mass defined as one-twelfth of the atomic mass unit. This study employs Hartree-Fock-Bogoliubov (HFB) theory to explore the density distributions of these isotopes. By calculating and comparing the neutron and proton densities, we aim to elucidate the variations in nuclear structure among different carbon isotopes and provide insights into the impact of pairing correlations and other nuclear phenomena on their spatial distributions.

Theory

Hartree Fock Bogoliubov theory (HFB) [3] is the generalized single particle model in which both Hartree Fock and BCS theory are given equal status. In HFB approximation, quasiparticle states are used instead of the single-particle states. Nuclear wave function is expressed in terms of the vacuum of suitable quasiparticles.[4] The matrix form of HFB equation is given by

$$\begin{pmatrix} h-\lambda & \Delta \\ -\Delta^* & -h^*+\lambda \end{pmatrix} \begin{pmatrix} U_n \\ V_n \end{pmatrix} = E_n \begin{pmatrix} U_n \\ V_n \end{pmatrix} \tag{1}$$

where $h = t+\Gamma$, E_n is the quasiparticle energy and λ is the chemical potential.

In the mean-field part, we have used the zero range Skyrme interaction with SLY4 parametrization, and in the pairing part, we have used density-dependent delta interaction with the mixed variant employed[5]. Treatment of isotopes with odd neutron numbers is based on equal filling approximation[6].

HFB equations have been solved using an axially deformed cylindrically symmetric harmonic oscillator basis.

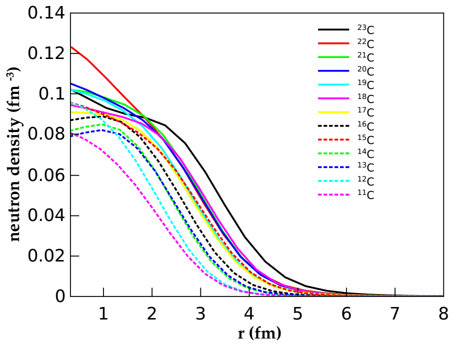

FIG. 1: Neutron density as a function of radial distance of $^{12-23}$C isotopes.

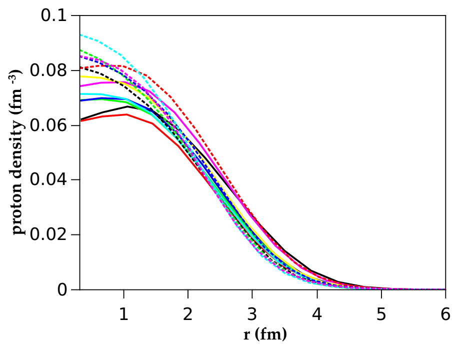

FIG. 2: Same as fig.1, but for proton distribution.

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Result and discussion

We systematically studied the structural properties of $^{11-23}$C isotopes using HFB theory. Our study investigated the density distribution of neutrons and protons in the carbon isotopes. For any isotope, the nuclear density distribution function describes the spatial distribution of nucleons.

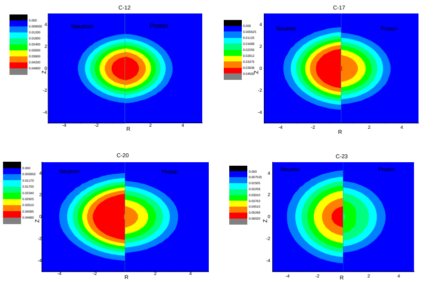

FIG. 3: Comparison of neutron and proton density distribution (left side - neutron, right side - proton.

The fluctuation of the density distribution of protons and neutrons as a function of radial distance with increasing neutron number is displayed in Fig. 1 and 2.

Fig. 3 shows the contour plot illustrating the density distribution of the C isotopes, with N = 6, 11, 14, and 17 as representatives. All the other isotopes of C also exhibit similar distributions. This illustration provides significantly more information on the isotope density distribution. The neutron density profile reveals how the spatial extension of neutron density increases with the neutron number. Notably, the neutron density in carbon isotopes rises with the mass number. Specifically, the isotope ^{22}C exhibits a higher neutron density compared to other carbon isotopes, indicating that ^{22}C is a neutron halo nucleus.

In contrast, the proton density is concentrated in a smaller region and remains relatively consistent across the different carbon isotopes. ^{12}C demonstrates a high proton density, reflecting its balanced proton-to-neutron ratio.

Comparing the neutron and proton density profiles, it is evident that the neutron density is higher than the proton density in carbon isotopes. This observation highlights the distinct distribution characteristics of neutrons and protons within these nuclei.

The density distribution provides information about the mass distribution of nucleons. In the plots, proton and neutron densities are plotted against nuclear radial distance, allowing for visualization of an approximate nuclear radius. The density distributions are plotted using the SLY4 density functional. From these plots, a nearly spherical density distribution is evident. In ^{12}C, the neutron and proton densities are similar. Notably, the odd carbon isotopes exhibit higher density distributions compared to their neighbouring isotopes.

Additionally, our preliminary calculations on halo nuclei, particularly focusing on neutron density distributions, suggest that further investigation is necessary. Extending this study will provide more comprehensive insights into the properties of neutron halos and their implications.

Understanding carbon isotopes' neutron and proton density distribution is crucial, particularly when considering their implications for nuclear reactions and stability. The extended nature of the neutron distribution not only influences scattering processes but also suggests new pathways for exploring the limits of nuclear existence, where weakly bound states may lead to novel reaction mechanisms.

References

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