Cluster structure in ^{24}C

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Introduction

Relativistic Hartree-Bogoliubov [RHB] [1] approach is widely used to study many-body problems in nuclear physics. It can also be applied to investigate nuclear clustering. The underlying benefit of relativistic mean-field theories is that they consider both the scalar and vector fields in the nucleus.

Cluster models in nuclear physics have concentrated mainly on clusters linked to the closure of the three-dimensional harmonic oscillator, such as ^{4}He and ^{16}O, where the impact of non-central forces like spin-orbit and tensor interactions is minimal [2]. The shell closure regions provide exciting observations. It becomes significant to examine neutron-rich clusters whose neutron numbers align with the sub-closure of the jj-upper orbits, where the spin-orbit interaction has an attractive effect. Neutron-rich clusters like those of ^{8}He in ^{24}C nucleus have a neutron number N = 6, corresponding to the sub-closure of $p_{3/2}$ sub-shell. The nucleus ^{8}He is located at the drip-line and has a neutron-halo structure [3]. Studies show that the magic number 8 weakens near the neutron drip line, while N = 6 may emerge as a new magic number [4]. Neutron-rich light nuclei play a vital role in the formation of r-process seed nuclei during radioactive capture reactions.

Theoretical Formalism

Applying variation principle to RHB equations, in the Hartree approximation for the self-consistent mean field, the relativistic Hartree-Bogoliubov equations read

$$\begin{pmatrix} h_D - \lambda - m & \Delta \\ -\Delta^* & -h_D^* + \lambda + m \end{pmatrix} \begin{pmatrix} U_k \\ V_k \end{pmatrix} = E_k \begin{pmatrix} U_k \\ V_k \end{pmatrix}$$

where, h_D is the single neutron Dirac Hamiltonian, Δ is the pairing field, m, the nucleon mass, E_k represents the quasi particle energy, and U_k, V_k are the RHB wave functions.
For ground state solution of an even-even nucleus, the Dirac equation for the Dirac spinors $\bar{\psi}$ leads to,

$$-i\alpha\nabla + \beta M^*(r) + V(r)\psi_i(r) = \epsilon_i \psi_i(r)$$

where we assume that the time-reversal invariance is valid. The Dirac effective mass is defined $M^* = m + \alpha_s\rho_s + \delta_s\Delta\rho_s$ while the vector potential reads $V(r) = \alpha_v\rho_\nu + \alpha_{TV}\tau_3\rho_{t\nu} + eA_0 + \Sigma_0^R$. Rearrangement contribution Σ_0^R reads,

$$\sum_0^R = \frac{\partial\alpha_s}{\partial\rho_\nu}\rho_s^2 + \frac{\partial\alpha_V}{\partial\rho_\nu}\rho_\nu^2 + \frac{\partial\alpha_{TV}}{\partial\rho_\nu}\rho_{t\nu}^2$$

The detailed theoretical formalism can be found in reference [5]. We have used the density dependent point coupling DD-PC1 [6] functional for our calculations.

Results and Discussion

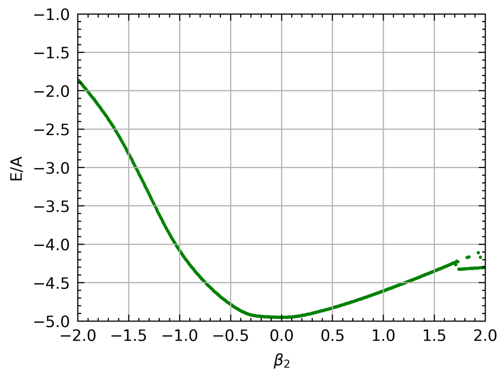

FIG. 1: Total energy per nucleon (E/A) in MeV against the deformation parameter β_2 for ^{24}C nucleus.

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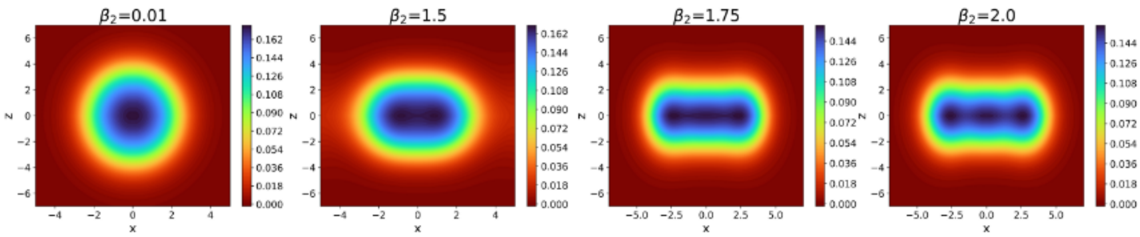

FIG. 2: Density distribution profile of ^{24}C nucleus obtained with DD-PC1 functional at different deformations values.

Fig. 1 depicts the change in energy per nucleon for the ^{24}C nucleus with deformation parameter β_2. The negative and positive value of β_2 depicts an oblate and prolate nucleus respectively. The energy per nucleon decreases as deformation increases and reaches a minimum energy state at $\beta_2 = 0.01$ corresponding to a prolate shape. To understand the structure of the nucleus at this deformation, a density distribution profile plotted within the RHB framework is presented in Fig 2.

As we increase the deformation we can observe the formation of a localized region at $\beta_2 = 1.5$. With further increase in deformation, i.e β_2 approaches a values of 1.75 or 2, the formation of three separate regions with a higher density distribution becomes visible. This structures can be attributed to the formation of the neutron rich cluster of ^{8}He as proposed in ref. [7].

Conclusion

Here we study the cluster structure of the neutron drip-line nucleus, ^{24}C. We found that the ground state of the nucleus is showing a prolate shape with $\beta_2 = 0.01$. At higher deformation it forms a three distinct cluster structure of ^{8}He. A further study of nucleon localization function and cluster modes are under progress.

Acknowledgments

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