Comparison of nuclear surface diffuseness between spherical and deformed nuclei in the island of inversion

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An extensive source of information on the nuclear surface of exotic nuclei have been their density profiles. The occupation probability near the Fermi level is directly related to the nuclear surface diffuseness, which increases when the nucleons are in the low orbital angular momentum state. This implies that the nuclear surface diffuseness is highly sensitive to the occupation of the nucleon in the distinct nuclear orbits and that it would be worthwhile to conduct a systematic analysis of the nuclear surface diffuseness. The present authors showed that the central depressed density like "bubble nuclei" have a sharper nuclear surface [1]. The nuclear deformation plays a crucial role in hindering bubble structure formation. Interestingly, there exists a so-called island of inversion [2], in the medium mass region, where the intruder configurations with particle-hole excitations across the N = 20 shell gap in their ground states cause large deformation. As a result, deviation from expected estimates from the conventional shell model are anticipated in this region. The fully microscopic antisymmetrized molecular dynamics (AMD) with the Gogny-D1S interaction has been employed to calculate the nuclear deformations of Ne isotopes [3]. According to their findings, at N = 19-28, there is an abrupt increase in the quadrupole deformation, β_2, as the Nilsson orbitals originating from the spherical $0f_{7/2}$ shell get filled for Ne isotopes.

We have investigated the relationship between the nuclear diffuseness and the spectroscopic information of the nuclei in Ref. [4]. We found that the increased neutron occupancy in the $1p_{3/2}$ orbit could cause the large surface diffuseness of Ne and Mg isotopes in the island of inversion. To extend this work, in this contribution, we will present how nuclear diffuseness is affected by deformation. To address this question, we extract the surface diffuseness of Ne isotopes from AMD densities, with and without the deformation.

Formalism

In this section, we will present a brief description of the nuclear microscopic structure model AMD [4, 5], as a precursor to calculating the density distribution of Ne isotopes. For a system of nucleons with mass number A, the Hamiltonian is given by

$$H = \sum_{i=1}^{A} t_i - t_{\rm cm} + \sum_{i<j}^{A} v_{ij}, \qquad (1)$$

where v_{ij} is the Gogny D1S density functional plus Coulomb interaction. The center-of-mass kinetic energy $t_{\rm cm}$ is removed without approximation. The parity-projected Slater determinant of nucleon wave packets is the variational wave function

$$\Phi^\pi = P^\pi \mathcal{A}\{\varphi_1 \cdots \varphi_A\}, \qquad (2)$$

where P^π denotes the parity ($\pi = \pm$) projector. The Gaussian form of the nucleon wave packets is

$$\begin{aligned}\varphi_i = \; & \prod\nolimits_{\sigma=x,y,z} \exp\{-\nu_\sigma (r_\sigma - Z_{i\sigma})^2\} \\ & \times \left(a_i \chi_{\frac{1}{2},\frac{1}{2}} + b_i \chi_{\frac{1}{2},-\frac{1}{2}}\right) (|p\rangle \text{ or } |n\rangle). \quad (3)\end{aligned}$$

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The ground state wave function can be written as,

$$\Psi_M^{J\pi} = \sum_{iK} g_{iK} P_{MK}^J \Phi^\pi(\beta_i), \tag{4}$$

where the deformation parameter β is used as a generator coordinate. P_{MK}^J is the total angular momentum projector and the coefficients g_{iK} and the ground state energy are found by solving the Hill-Wheeler equation. The point nucleon densities can be written as

$$\rho_{JM}(\boldsymbol{r}) = \langle \Psi_M^{J\pi} | \textstyle\sum_i \delta^3(\boldsymbol{r}_i - \boldsymbol{r}_{cm} - \boldsymbol{r}) | \Psi_M^{J\pi} \rangle \tag{5}$$

where $\boldsymbol{r}_{cm}$ is the center-of-mass coordinate. The density distribution $\rho_{JM}(\boldsymbol{r})$ will be used to extract nuclear diffuseness. For more details on the AMD and the associated formalism one is referred to Refs. [3–5].

Results and discussions

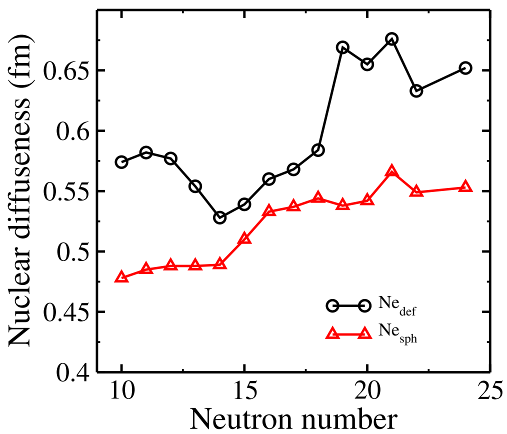

FIG. 1: Ne_{def} and Ne_{sph} shows the nuclear surface diffuseness extracted fron deformed and "spherical" AMD densities, respectively.

To determine the nuclear surface diffuseness, we used a two-parameter Fermi (2pF) distribution for nuclear matter density as,

$$\rho_{2pF}(r) = \frac{\rho_0}{1 + \exp\left[(r - R)/a\right]}, \tag{6}$$

with a and R as the diffuseness and radius parameters, respectively. The normalization condition, $\int \rho(r) d\boldsymbol{r} = A$, with '$A$' as the mass number, determines the value of ρ_0 for a given a and R.

This gives us the freedom to extract the diffuseness parameters from any arbitrary density distribution $\rho(r)$ by minimizing the quantity

$$\frac{4\pi}{A} \int_0^\infty |\rho(r) - \rho_{2\mathrm{pF}}(r)| r^2 dr. \tag{7}$$

In our case $\rho(r)$ will be the calculated AMD density distribution. The extracted diffuseness, as per Eq. 7, are shown in Fig. 1. Ne_{def} shows the nuclear surface diffuseness extracted from AMD density which has deformation effects properly incorporated. Ne_{sph}, on the other hand, are for surface diffuseness extracted from AMD density with a zero deformation (spherical nuclei). The diffuseness parameter depends on the neutron number as well as the nuclear deformation [3]. The importance of deformation is also highlighted by the fact that diffuseness extracted from Ne_{def} are about 20% higher in magnitude than those from Ne_{sph}. We will also show that the mixing of lower orbital angular momentum states leading to enhanced deformation around the Fermi levels makes the nuclear surface more diffuse.

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