Exploring the bubble nature of ^{22}O

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Introduction

The density profile of nuclei have abundant source of the structure information. Most of the nuclei have a constant nuclear density in the core and a gradually decreasing density near the surface region. “Bubble” nuclei, on the other hand, have a central depletion in their density profile. Recently, using the γ-ray spectroscopy, a central depletion of proton density in ^{34}Si unstable nucleus was reported experimentally [1]. The distinct nuclear orbits are the primary indication in the formation of these nuclei. If s-orbitals are vacant, then the interior density of the nuclei becomes depleted, and bubble-like structure may be formed. In general, the central depletion occurs when the occupancy of nucleons in the single-particle orbit with the low angular momentum is reduced. The present authors showed that the central portion of the nuclear density profile is not probed by the proton scattering through the nuclear surface region can be investigate [2]. By studying the cross section at the first peak position of the elastic scattering differential cross section of proton-nucleus scattering one can extract the surface information of nuclei, where bubble structure have a prominent role. As a result, proton scattering could be a useful technique to investigate the bubble structure in the unstable nuclei.

In this contribution, we present a systematic analyses of the elastic scattering differential cross section of proton-^{22}O reaction to extract the information on nuclear bubble structure under the aegis of the high-energy nucleon-nucleus scattering within the Glauber model.

1. Formalism

The Glauber model provides a consistent framework of high-energy nuclear scattering [3]. Under normal kinematics, with proton incident on the target nucleus, the final state wave function of the target nucleus within the eikonal and adiabatic approximation can be written as,

$$|\phi_f\rangle = e^{i\chi}\,|\phi_i\rangle\,, \tag{1}$$

where $|\phi_i\rangle$ shows the initial state wave function of the target nucleus. $e^{i\chi}$ is the phase-shift function, which contains all the information regarding the nucleon-nucleus scattering. Ignoring multiple scattering, the phase-shift function for the nucleon-nucleus scattering in the Optical limit approximation is given by [2],

$$e^{i\chi_N(\boldsymbol{b})} \approx \exp\left[-\int d\boldsymbol{r}\rho_N(\boldsymbol{r})\Gamma_{NN}(\boldsymbol{b}-\boldsymbol{s})\right], \tag{2}$$

where $\boldsymbol{s}$ is the projection of $\boldsymbol{r}$ on the perpendicular plane of incident beam direction (z) and $\boldsymbol{b}$ is the impact parameter. $\rho_N(\boldsymbol{r})$ is the intrinsic density of the target nucleus. Γ_{NN} is the profile function of nucleon-nucleon collisions. The elastic scattering amplitude is given by,

$$F(\boldsymbol{q}) = \frac{iK}{2\pi}\int d\boldsymbol{b}\, e^{i\boldsymbol{q}\cdot\boldsymbol{b}}(1-e^{i\chi_N(\boldsymbol{b})}), \tag{3}$$

where K is the relative wave number and $\boldsymbol{q}$ is the momentum transfer vector of the incident nucleon. Now, the elastic scattering differential cross section can be evaluated by

$$\frac{d\sigma}{d\Omega} = |F(\boldsymbol{q})|^2. \tag{4}$$

2. Results and discussions

For ^{22}O, we consider two types of configurations $(0d)^6$ and $(0d)^4(1s)^2$ for outer most

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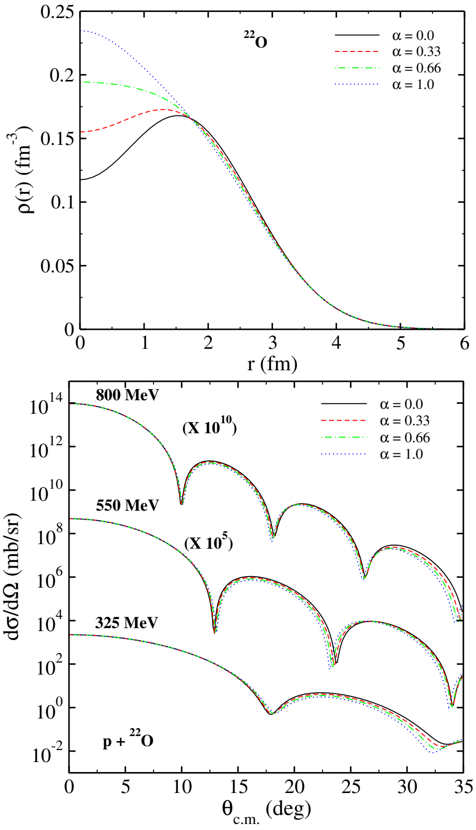

FIG. 1: Upper panel, Plots the HO density distribution and lower panel, plots elastic scattering differential cross sections of proton-^{22}O reactions at 325, 550, and 800 MeV with various α parameters.

nucleons in sd-shell, and corresponding densities as $\rho^d(r)$ and $\rho^s(r)$, respectively, within the harmonic-oscillator (HO) model calculated with center-of-mass correction [4]. Because of the vacancy in the 1s-orbit, $\rho^d(r)$ has most prominent bubble structure, whereas $\rho^s(r)$ does not. Then, we incorporate these two densities as,

$$\rho(\alpha; r) = (1-\alpha)\rho^d(r) + \alpha\rho^s(r), \qquad (5)$$

where the occupation probability is controlled by the mixing parameter α $(0 \leq \alpha \leq 1)$ in the 1s-orbit. As a result, the most bubbly density is shown by the $\alpha = 0$ and non-bubble density is shown by the $\alpha = 1$. The harmonic oscillator size parameter is chosen to reproduce the reaction cross-section of ^{22}O-^{12}C reaction at 965 MeV/u incident energy [5].

Figure 1 shows (upper panel) the matter density distribution of ^{22}O with various α parameters. The strong depressed central density, with $\alpha = 0$, clearly shows the bubble character. When α parameter increases, the contribution of 1s-orbits increases and bubble nature disappears. We then calculate the elastic scattering differential cross section of proton-^{22}O reaction [Figure 1 (lower panel)] at 325 MeV, 550 MeV and 800 MeV incident energies with various α parameters to see the signature of bubble nature in this reaction observable. It has been shown [2], that the cross section at the first diffraction peak of elastic scattering differential cross section is higher when nuclear surface diffuseness is small. As expected, we see that the cross section at the first diffraction peak is higher for ideal bubble character ($\alpha = 0$) and it is decreases when α increases. We will demonstrate that the bubble nuclei have sharper nuclear surface as compared to the non-bubble ones by studying their elastic scattering with hadronic probes.

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