Investigation of the structure of ^{20}Ne using proton elastic scattering†

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The α cluster structure plays an important role in elucidating the structure of light nuclei. Quantifying the degree of the clustering is one of the hot topics in the nuclear physics community. Recently, the presence of α cluster structure has been revealed in the proton elastic scattering cross sections of ^{12}C and ^{16}O, indicating a significant amount of 3α and 4α cluster components in their nuclear surfaces, respectively.[1] Building on this observation, here we investigate the structure of ^{20}Ne by proton elastic scattering using density distributions obtained with the antisymmetrized quasi-cluster model (AQCM) wave functions.[2] It is known that ^{20}Ne has a well-developed p-shell-closed ^{16}O plus α cluster structure in its energy spectra[3] and recently in the α knockout reaction.[4] However, ^{16}O has predominant 4α structure in the nuclear surface,[1] implying the presence of the 5α structure in ^{20}Ne. These differences are evident in the density distributions near the nuclear surface, which can be investigated by studying the proton-nucleus elastic scattering cross sections at the first diffraction peak.[5] In this study, in addition to investigating these cluster model configurations, the density distribution of the j-j coupling shell model is also prepared and compared.

Here, the proton elastic scattering cross sections are evaluated by the optical-limit approximation of the Glauber model using the density distributions obtained with the AQCM wave functions.[2] The AQCM is an extension of the Brink's cluster model enabling one to express the j-j coupling shell model state in addition to the cluster model states. The wave function of ^{20}Ne is the antisymmetrized ($\mathcal{A}$) product of the microscopic α cluster wave function and is given as

$$\Phi(\nu, d, d_5, \Lambda) = \mathcal{A}\left\{\prod_{i=1}^{5} \Phi_\alpha(\nu, \boldsymbol{R}_i, \Lambda)\right\}, \qquad (1)$$

where Φ_α is the wave function of the ith α particle, which is described by the product of the single-nucleon Gaussian wave packets with the size parameter ν. Four α particles ($i \leq 4$) are placed at the vertices of a tetrahedron with distance $d = |\boldsymbol{R}_i - \boldsymbol{R}_j|$, and the fifth α particle is placed on the z axis passing through this α and the center of the tetrahedron. The distance between the center of the tetrahedron and the fifth α particle is defined by d_5. In AQCM, the position vector is extended by setting the imaginary part as $\boldsymbol{R}_i \to \boldsymbol{R}_i + i\Lambda \boldsymbol{e}^{\rm spin} \times \boldsymbol{R}_i$, where $\boldsymbol{e}^{\rm spin}$ is a unit vector for the intrinsic spin configuration of a nucleon. With this extension, the AQCM wave function can express the j-j coupling shell-model configuration in the limit of the inter-cluster distance $d, d_5 \to 0$ with $\Lambda = 1$. In this study, we examine four configurations of ^{20}Ne by choosing appropriate combinations of the AQCM parameters, *i.e.*, ν, d, d_5, and Λ, to reproduce the experimental charge radius of ^{20}Ne: the j-j coupling and SU(3) shell model configurations, and 5α and $^{16}\mathrm{O}+\alpha$ (Oα) configurations.

Figure 1 compares the differential proton elastic scattering cross sections of ^{20}Ne with the four configurations obtained above. The incident proton energy is taken as 800 MeV, for which the experimental data are available. Comparing the theoretical cross sections with the experimental data, we see that the $^{16}\mathrm{O}+\alpha$ configuration is the most likely of the four configurations. Note that this result does not contradict the current understanding of the structure of ^{16}O as in the following interpretation: ^{16}O exhibits a well-developed 4α structure on the nuclear surface, which means that the configuration is not completely p-shell closed but contains sd-shell components. In ^{20}Ne, an additional α particle fills the vacant p-orbit, leading to the p-shell closed ^{16}O structure in ^{20}Ne. The extension of this study to heavier nuclear systems is underway.

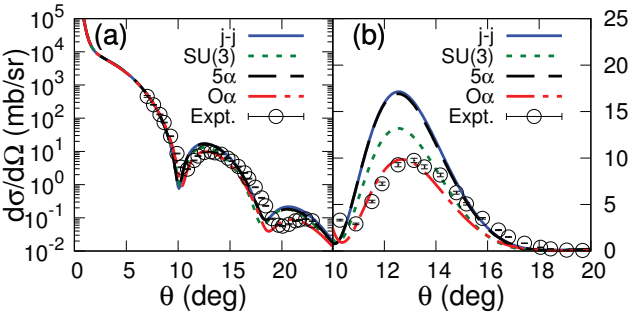

Fig. 1. Differential elastic scattering cross sections of p+^{20}Ne in (a) logarithmic and (b) linear scales. The experimental data are taken from Ref. 6).

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