Indication of α clustering in the density profiles of ^{44,52}Ti[†]

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The standard nuclear structure is shell structure; however, α-cluster structure often appears in the ground and excited states of light nuclei. Here, we discuss the α-cluster structure in medium mass nuclei, ^{44}Ti and ^{52}Ti, and show that the development of core+α structure can be quantified in the density profiles near the nuclear surface using proton-nucleus elastic scattering.

In the present study, we examine two different density profiles. Shell- and α-cluster configurations are generated by utilizing the basis states of the antisymmetrized quasi-cluster model (AQCM),[1)] which can describe both the j-j coupling shell and α-cluster configurations in a single scheme. The AQCM basis for the core (^{40}Ca or ^{48}Ca) plus α cluster is expressed by the antisymmetrized product of the core and α-cluster wave functions, with R being their distance. The wave function of the core nucleus is constructed based on the multi-α cluster model at the zero-distance limit, corresponding to the $N = 20$ closure for ^{40}Ca and eight neutrons are additionally put for the $N = 28$ closure of ^{48}Ca. The size parameters of the core and α-cluster wave functions are taken as the same for simplicity.

The shell-model wave functions for ^{44,52}Ti are obtained by taking $R \to 0$. The size parameter is fixed to reproduce the measured charge radius of ^{44}Ti or ^{52}Ti. We call this shell-model wave function as S-type.

For the α-cluster wave function, we determine the size parameter to reproduce the measured charge radius of the core nucleus and set the R value to reproduce the charge radius of ^{44}Ti or ^{52}Ti. We call this α-cluster wave function as C-type. The determined R value is large (2.85 fm) for ^{44}Ti, indicating a well-developed α-cluster structure. The charge radius of ^{52}Ti is not known. However, to understand the role of excess neutrons, we assume $R = 3$ fm for ^{52}Ti, which is comparable to that of ^{44}Ti.

Although both S- and C-types reproduce the charge radius data, we discover that α clustering significantly changes the density profiles near the surface. To quantify these changes, we evaluate the nuclear "diffuseness,"[2)] which is practically obtained by a two-parameter Fermi function, $\rho_0/\{1+\exp[(r-\bar{R})/a]\}$, where the radius ($\bar{R}$) and diffuseness ($a$) parameters are determined by the least-square fitting with the obtained one-body density. The a values for S- and C-types are 0.56 fm and 0.63 fm for ^{44}Ti and 0.58 fm and 0.61 fm for ^{52}Ti, respectively. The α clustering significantly changes the nuclear surface diffuseness, especially for ^{44}Ti, owing to the occupation of the diffused low-angular momentum orbit, *i.e.*, $1p$ orbit. For ^{52}Ti, the difference between S- and C-types is less significant that of ^{44}Ti because the shell-model configuration $(1p_{3/2})^4$ already has a diffused nuclear surface.

We show that this difference can be detected by measuring proton-nucleus elastic scattering at intermediate energies. The proton-nucleus differential elastic scattering cross sections are calculated by the optical-limit approximation in the Glauber model. Inputs to the reaction model are one-body density distributions and profile function. By using the standard profile function, we confirm that the theory reproduces the experimental cross sections for ^{40}Ca and ^{48}Ca using the wave functions obtained by the AQCM approach without introducing any adjustable parameter.

Figure 1 plots the proton-nucleus differential elastic scattering cross sections at 320 MeV/nucleon at around the first peak position, where the difference of the nuclear diffuseness is well reflected.[2)] For ^{44}Ti, we see that the difference between the S- and C-type cross sections is large, considering that the uncertainties of the experimental proton-^{40}Ca cross sections at around the first peak position is only $\approx$4%.[3)] The difference is smaller for ^{52}Ti, but it is significant.

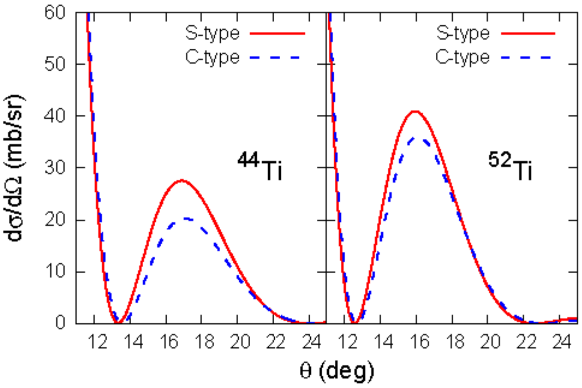

Fig. 1. Proton-^{44,52}Ti differential elastic scattering cross sections at 320 MeV/nucleon for scattering angles near the first peak position.

In summary, we have investigated the density profiles of ^{44}Ti and ^{52}Ti with the shell and α-cluster configurations and found that these two aspects can be distinguished by measuring the proton-nucleus differential elastic scattering cross sections up to the first peak position.

References

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