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Nucleon density distribution of proton drip-line nucleus ^{17}Ne

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Abstract. ^{17}Ne is one of the candidates for proton halo nuclei. To study the halo structure of ^{17}Ne, we measured the reaction cross-sections (σ_R) and deduced the density distribution of ^{17}Ne through the energy dependence of σ_R. From the deduced density, it is found that ^{17}Ne has a long density tail which is consistent with the picture of two valence protons of ^{17}Ne occupying the $2s_{1/2}$ orbital.

PACS. 25.60.Dz Interaction and reaction cross-sections

1 Introduction

It is interesting to study the proton halo structures that are less known compared to the neutron halo structures, in order to obtain a detailed understanding of the mechanism of halo formation in loosely bound nuclei. While several neutron halo nuclei have been found and well studied in the p-shell (*e.g.* ^{11}Li [1]) and sd-shell (*e.g.* ^{14}Be, ^{17}B [2]) regions, only one proton-halo nucleus, namely ^{8}B, has been reported [3]. The ground state of proton drip-line nucleus ^{17}Ne($I^{\pi} = 1/2^{-}$) was suggested to have a proton halo structure, on the basis that the interaction cross-section (σ_I) for ^{17}Ne at relativistic energies are larger than those for the mirror nucleus ^{17}N [4]. Several experiments have been performed to verify the hypothesis but the results conflict with each other [5]. If, indeed, ^{17}Ne has a proton halo structure, it will be the first proton-rich nucleus in the sd-shell region to have a two-proton halo structure.

Another intriguing question that could be answered by the study on ^{17}Ne concerns the possibility of existence of a new magic number $Z = 16$. The new magic number $N = 16$ has been discovered for some neutron-rich nuclei [6]. The orbital that two valence protons could occupy is either the $1d_{5/2}$ or the $2s_{1/2}$, and it is not easy to discriminate the two possibilities in an experiment. If the two valence protons mainly occupy $2s_{1/2}$, for which the centrifugal barrier becomes low, the proton density distribution for ^{17}Ne will have a long tail. In this case, the level energy of $2s_{1/2}$ should be lower than $1d_{5/2}$, which can lead to the occurrence of magic number 16 [6].

To study the structure of ^{17}Ne, we have measured the reaction cross-sections (σ_R) at several tens of A MeV to deduce the density distribution of ^{17}Ne. In this energy range, the nucleon-nucleon total cross-section (σ_{NN}) becomes large [7], therefore σ_R becomes sensitive to the dilute-density at the nuclear surface.

2 Experiment

The experiment was carried out at the RIKEN Accelerator Research Facility. A primary beam of 135 A MeV ^{20}Ne provided by the RIKEN Ring Cyclotron was impinged on a ^{9}Be production target to produce a ^{17}Ne beam. The ^{17}Ne secondary beam was separated from other reaction products through the RIKEN Projectile fragment Separator. The σ_R for ^{17}Ne on ^{9}Be, ^{12}C and ^{27}Al targets at 64 A MeV and 42 A MeV were measured by means of the transmission method to within 2% accuracy.

3 Density distribution

In this study, the σ_R is related to a density distribution through the optical limit of the Glauber theory (OL). We

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Table 1. Reaction and interaction cross-sections for ^{17}Ne used in the fitting procedure.

Target	Energy (A MeV)	σ_I (mb) [4]	σ_R (mb)
Be	700	968 ± 45	
	64		1249 ± 25
	42		1467 ± 33
C	680	1090 ± 76	
	620	1044 ± 31	
	64		1331 ± 27
	42		1541 ± 31
Al	670	1412 ± 224	
	64		1795 ± 36
	43		2012 ± 40

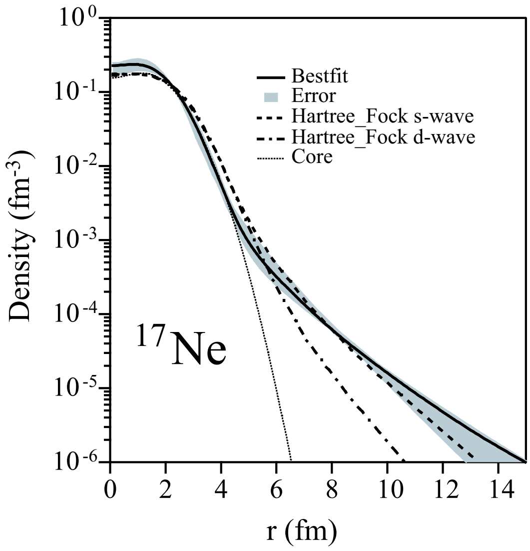

Fig. 1. Density distribution of ^{17}Ne. The error indicated contains the experimental and also the ambiguity of the fitting method.

deduced the density distribution of ^{17}Ne via a fitting procedure using the present σ_R data and the σ_I data at high energies [4]. The fitting procedures are as follows. First, a calculation is performed to obtain an initial value for σ_R (σ_R^{calc}), using the OL with an assumed density distribution. Next, the σ_R^{calc} is compared with the experimental σ_R. If σ_R deviates from the experimental σ_R, the assumed density distribution is adjusted, and the calculation is repeated to obtain a new σ_R^{calc}. Repeating these procedures, the best-fit density distribution of ^{17}Ne was obtained. In our calculation, we assumed the harmonic-oscillator (HO) type function plus single-particle densities as a functional form of the proton density. The single-particle density was calculated with the Woods-Saxon potential, the Coulomb and centrifugal barriers. The HO function with the same width was assumed for the neutron density. The free parameters were the width of the HO function, the separation energy of valence protons, and the fractions of $1d_{5/2}$ and $2s_{1/2}$ orbitals. Table 1 shows the σ_I and σ_R for ^{17}Ne used in the present fitting.

In deducing the density distribution, we have considered the following three corrections. First, we corrected the σ_R calculated with the OL. In the lower energy region, as in the case of the present experiment, there is a discrepancy between the experimental σ_R and the one calculated with the OL even for stable nuclei. This discrepancy was corrected by using the ratio of the experimental σ_R to that obtained with the OL calculation for stable nuclei. In the present analysis, the σ_R calculated with the OL were always corrected by multiplying by this ratio [8].

Secondly, we considered the effect of the few-body approximation of Glauber theory (FB), which was proposed by Ogawa *et al.* and Al-Khalili *et al.* [9], because the FB is more appropriate than the OL for dilute densities. Since it is difficult to apply FB, instead of OL, directly to the fitting procedure, correction for the FB effect was done as follows. The experimental σ_R were multiplied by the ratio of σ_R with the FB to that calculated with the OL. Here, both σ_R were calculated using the same density distribution deduced through the OL fitting to the experimental σ_R. Then these few-body corrected σ_R (σ_R^{FB}) were used in the fitting with the OL again. Repeating this procedure, σ_R^{FB} and the density distribution converged into the final results.

Lastly, correction for the effect of the Fermi motion was also taken into account in the FB calculation, which is considered to be important at low energies because of a finite reaction time neglected in the Glauber theory.

Figure 1 shows the deduced density distribution of ^{17}Ne. For comparison, the theoretical densities calculated by Kitagawa *et al.* [10] with the Hartree-Fock model, in which two valence protons occupy the $2s_{1/2}$ orbital or $1d_{5/2}$ orbital, are also shown in this figure. The deduced density distribution of ^{17}Ne has a long density tail, consistent with the theoretical one for which two valence protons are in the $2s_{1/2}$ orbital. This fact implies the level inversion of $2s_{1/2}$ and $1d_{5/2}$, and therefore, the possible occurrence of the magic number 16 on the proton-rich side.

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