A directly measurable parameter quantifying the halo nature of one-neutron halo nuclei†

S. Watanabe,*1 M. Yahiro,*2 M. Toyokawa,*2 and T. Matsumoto*2

After the discovery of a halo nucleus ^{11}Li[1)], total reaction cross sections ($\sigma_{\rm R}$) and/or interaction cross sections ($\sigma_{\rm I}$) were further measured to identify new halo nuclei[2)]. For example, it was established that ^{11}Be and ^{15,19}C are one-neutron halo nuclei, and ^{6}He, ^{11}Li, ^{14}Be, and ^{22}C are two-neutron halo nuclei with Borromean structures. Nowadays, the measurements reach the pf-shell region, i.e., the vicinity of the neutron-drip line for Ne and Mg isotopes[3,4)]; ^{31}Ne and ^{37}Mg are considered to be one-neutron halo nuclei[6,7)]. Thus, the sudden enhancement of measured $\sigma_{\rm R}$ is a good experimental probe of halo nuclei. However, the relation between $\sigma_{\rm R}$ and the separation energies of the halo nuclei are not well understood particularly in the weak-binding limit.

In this report, we focus on the scattering of one-neutron halo nuclei (a) on a target (T) at high incident energies ($E_{\rm in} \gtrsim 240$ MeV/nucleon) where projectile-breakup effects are expected to be small. At the high incident energies, we can identify $\sigma_{\rm R}$ and $\sigma_{\rm I}$ as absorption cross sections $\sigma_{\rm abs}$. We also assume that one-neutron halo nuclei (a) are well described by the core + neutron ($c+n$) two-body model, and the scattering of a on T is well explained by the $c+n+$T three-body model. We now propose the parameter

$$\mathcal{H} = \frac{\sigma_{\rm abs}(a) - \sigma_{\rm abs}(c)}{\sigma_{\rm abs}(n)}, \qquad (1)$$

where $\sigma_{\rm abs}(x)$ is the absorption cross section of x on the same T at the same incident energy per nucleon. The parameter $\mathcal{H}$ represents an enhancement of $\sigma_{\rm abs}(a)$ from $\sigma_{\rm abs}(c)$ relative to $\sigma_{\rm abs}(n)$, and varies in a range of $0 \le \mathcal{H} \le 1$. The halo structure is most developed when $\mathcal{H} = 1$ and least developed when $\mathcal{H} = 0$[5)]. Therefore, $\mathcal{H}$ is expected to quantify the degree of halo nature regardless of scattering conditions such as $E_{\rm in}$ or T.

Figure 1 shows the behavior of $\mathcal{H}$ as a function of the one-neutron separation energy S_n. Experimental data is listed in Ref.[5)]. The results of the present model[5)], which is based on the spherical Woods-Saxon potential and the Glauber model, are consistent with the empirical values for all halo nuclei ^{11}Be, ^{19}C, ^{31}Ne and ^{37}Mg within 1σ error bars. $\mathcal{H}$ is then extrapolated to the $S_n = 0$ limit as shown by the lines. Only for s-wave halo nuclei ^{11}Be and ^{19}C, the lines reach $\mathcal{H} = 1$ in the $S_n = 0$ limit. On the other hand, the lines saturate at about 0.55 for p-wave halo nuclei ^{31}Ne and ^{37}Mg, and at about 0.21 for a d-wave non-halo nucleus ^{17}C. As a result, the five lines are well separated into three groups of s-wave halo, p-wave halo and d-wave non-halo in the vicinity of $S_n = 0$. If s-wave halo nuclei with very small separation energy ($S_n \lesssim 0.01$ MeV) are newly discovered, they should be on or near the line. This may be also true for p-wave halo nuclei. Therefore, if $\sigma_{\rm R}(n)$, $\sigma_{\rm R}(c)$ and $\sigma_{\rm R}(a)$ are newly measured at the same incident energy per nucleon, one can derive $\mathcal{H}$ and see the halo nature of the nuclei without model calculation. $\mathcal{H}$ is thus a good indicator quantifying the halo nature of one-neutron halo nuclei.

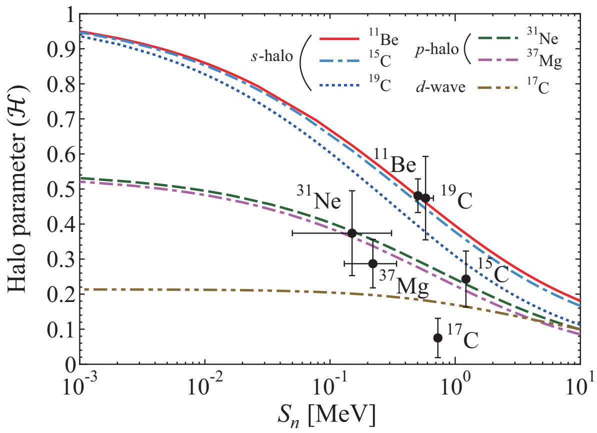

Fig. 1. Behavior of $\mathcal{H}$ as a function of S_n. The horizontal axis is in the logarithmic scale. The theoretical results are shown by the solid (dotted) line for ^{11}Be (^{19}C), the dashed (dot-dashed) line for ^{31}Ne (^{37}Mg), the dot-dot-dashed line for ^{17}C, and the dot-dashed line for ^{15}C. See Ref.[5)] for the experimental data.

References

1) I. Tanihata et al., Phys. Rev. Lett. **55**, 2676 (1985); Phys. Lett. B **206**, 592 (1988).
2) A. Ozawa et al., Nucl. Phys. A **691**, 599 (2001).
3) M. Takechi et al., Phys. Lett. B **707**, 357 (2012).
4) M. Takechi et al., Phys. Rev. C **90**, 061305(R) (2014).
5) M. Yahiro et al., Phys. Rev. C **93**, 064609 (2016).
6) K. Minomo et al., Phys. Rev. Lett. **108**, 052503 (2012).
7) S. Watanabe et al., Phys. Rev. C **89**, 044610 (2014).

† Condensed from the article in Phys. Rev. C **93**, 064609 (2016)
*1 RIKEN Nishina Center
*2 Department of Physics, Kyushu University