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Reaction cross-sections for stable nuclei and nucleon density distribution of proton drip-line nucleus ^{8}B

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Abstract. The optical limit of the Glauber theory with zero-range approximation, which is successfully used at high energies to connect the nucleon density distribution with reaction cross-sections (σ_R), gives somewhat smaller values of σ_R by 10–20% at intermediate energies. We have precisely measured the σ_R for ^{12}C on Be, C, and Al at 30A–200A MeV, and for ^{9}Be on Be at 70A–100A MeV to investigate the enhancement of σ_R compared to the optical-limit calculation. From the enhancements, we deduced the nucleon-nucleon range as a function of energies. We deduced the density distribution of ^{8}B analyzing the known experimental σ_R for ^{8}B with an enhancement correction or with the finite range effect as a test.

PACS. 25.60.Dz Interaction and reaction cross-sections

1 Introduction

The measurement of reaction cross-sections (σ_R) allows one to deduce the nucleon density distribution using the Glauber calculation (optical limit of the Glauber theory with zero-range approximation). Especially, σ_R at intermediate energies of several tens MeV/nucleon are considered to be quite sensitive to dilute nucleon densities, like a halo, because of the large σ_{NN} at those energies. However, it is known that the Glauber calculation underestimates σ_R by 10–20% at intermediate energies and this disagreement causes a relatively large systematic error in the deduced density distribution.

In order to clarify the problem and to correct for the disagreement, we measured the σ_R of stable nuclei precisely, and investigated the enhancement of the experimental σ_R compared to the Glauber calculation. As a test, we deduced the density distribution of ^{8}B analyzing the known experimental σ_R [1] with the enhancement correction or with the finite range effect.

2 Experiment

We have precisely measured the σ_R for ^{12}C beams on Be, C and Al targets and ^{9}Be beams on Be target in the energy region of 30A–200A MeV, where there was a lack of precise and systematic σ_R data for stable nuclei. The primary beams of ^{12}C with energies of 75A, 100A, 180A, and 230A MeV were used, which were provided from the HIMAC [2] synchrotron. ^{9}Be beams were produced through the projectile fragmentation process in ^{12}C + ^{9}Be collision. The transmission method was employed to measure the σ_R. The schematic view of the experimental setup is shown in fig. 1. The nuclei produced in a production target were separated by magnetic rigidity analysis and identified by time of flight and ΔE. Two thin plastic scintillators (0.2 and 0.1 mm thick) placed upstream of the target were used for the identification of incoming particles to count the number of incident nuclei (N_0). Four

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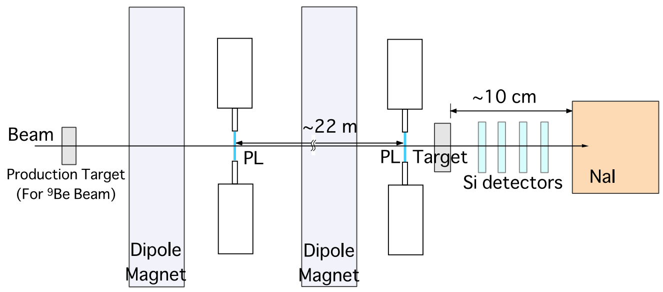

Fig. 1. Schematic view of the experimental setup.

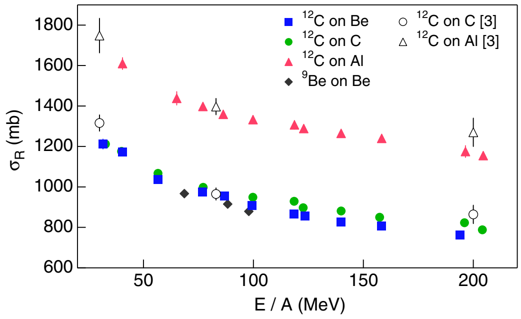

Fig. 2. Experimental results.

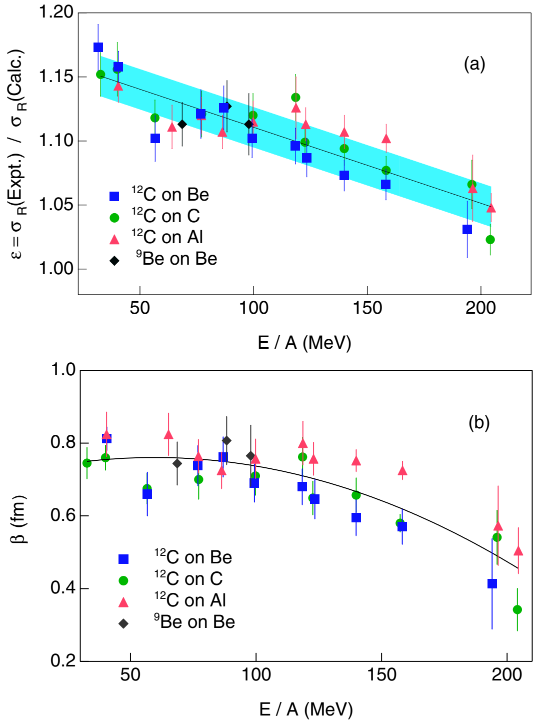

Fig. 3. (a) Deduced ε and (b) deduced NN range.

Si ΔE counters (400 or 500 μm thick) and a NaI(Tl) energy counter (76.2 mm ϕ, 60 mm thick) placed downstream of the target composed a counter telescope, for the identification of A and Z of outgoing particles to count the number of events without any nuclear reactions in the target (N_1). The σ_R is determined as,

$$\sigma_R = -\frac{1}{t} \ln \frac{N_1}{N_0},$$

where t is the target thickness. However, the ratio N_1/N_0 must be corrected for nuclear reactions in the detectors. For this purpose, the measurement without the reaction target was also carried out in the same condition.

3 Results and discussion

In fig. 2, experimental results on the reaction cross-section σ_R are plotted as functions of beam energy. We also plot the σ_R reported by Kox *et al.* [3] with the open symbols. The present data agree with their data within the errors, while the accuracy is improved.

We compared our experimental σ_R with the Glauber calculations, and the enhancement factor is defined by the ratio of the experimental value over the calculation as $\varepsilon \equiv \sigma_R(\text{Expt.})/\sigma_R(\text{Calc.})$. In fig. 3(a), we plotted the obtained ε as a function of beam energy. Experimental σ_R exceed the calculations by $\sim 15\%$ at $40A$ MeV, and $\sim 5\%$ at $200A$ MeV. The ε data seem to be independent of the combination of projectile and target nuclides. We fitted a line to the ε data as shown in fig. 3(a) [$\varepsilon(E)$]. We used $\varepsilon(E)$ as a correction factor to the Glauber calculation in the analysis for the density distribution of ^{8}B.

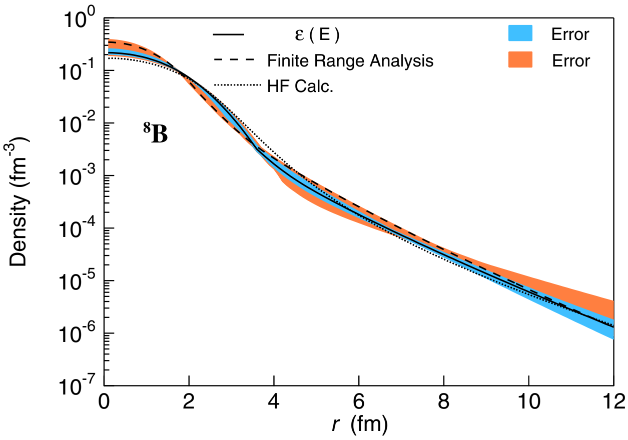

Fig. 4. The deduced density distribution of ^{8}B.

In the above analysis, we assumed zero-range approximation. However, this approximation may not be appropriate at intermediate energies. We deduced the range of nucleon-nucleon interaction (NN range) from our data, assuming the enhancement of σ_R is due to the finite range effect. In fig. 3(b), the deduced NN ranges (β) are plotted as a function of beam energy. The NN ranges should be the same for any nuclides. However, the deduced values seem to have a slight dependence on the combination of projectile and target nuclides. We fitted a polynomial function to the obtained ranges (solid line). Using this range function [$\beta(E)$], we analyzed density distribution of ^{8}B with the finite range Glauber calculation.

Figure 4 shows the deduced density distribution of ^{8}B using the $\varepsilon(E)$ (solid line) and using the finite range

Glauber calculation (broken line). The error of the density distribution is shown with the shaded area. The error of the density distribution obtained by the finite range analysis is relatively large due to the slight target dependence of the effective NN range. It is seen that both density distributions are consistent with the Hartree-Fock (HF) calculation [4] (dotted line) at the tail part.

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