Measurement of the total reaction cross section for the mirror nuclei ^{12}N and ^{12}B*

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Abstract The mirror nuclei ^{12}N and ^{12}B are separated by the Radioactive Ion Beam Line in Lanzhou (RIBLL) at HIRFL from the breakup of 78.6 MeV/u ^{14}N on a Be target. The total reaction cross-sections of ^{12}N at 34.9 MeV/u and ^{12}B at 54.4 MeV/u on a Si target have been measured by using the transmission method. Assuming ^{12}N consists of a ^{11}C core plus one halo proton, the excitation function of ^{12}N and ^{12}B on a Si target and a C target were calculated with the Glauber model. It can fit the experimental data very well. The characteristic halo structure for ^{12}N was found with a large diffusion of the protons density distribution.

Key words mirror nuclei ^{12}N and ^{12}B, total reaction cross section, Glauber model

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1 Introduction

In the past decades projectile fragmentation has been widely used to study the reaction mechanism of heavy ion collisions. Since the discovery of neutron skin and neutron halo nuclei, such as ^{11}Li and ^{11}Be, etc, [1, 2] interest in the study of very neutron-rich and proton-rich nuclei has grown in view of their anomalous structures. The structure of exotic neutron-rich or proton-rich nuclei has been investigated in considerable detail through measurements of the total reaction cross section or interaction cross section, fragment momentum distribution in fragmentation reactions, quadrupole moments and Coulomb dissociation. The neutron skin or halo nuclei ^{6}He, ^{8}He, ^{11}Li, ^{11}Be, ^{14}Be, ^{19}C, etc, have been identified by these experimental methods. Due to the centrifugal and Coulomb barriers, the formation of a proton halo is more difficult compared to a neutron halo.

The proton-rich nucleus ^{12}N has a very small separation energy (S_p=0.6 MeV). It satisfies a (necessary but not sufficient) criterion given by Hansen et al. for the existence of a halo: $S\times A^{2/3}\approx 2$ to 4 MeV [3]. Interaction cross sections for ^{12}N on Be, C and Al targets have been measured at 700 MeV/u by Ozawa et al [4]. A halo structure has been revealed. Warner et al. measured the total reaction cross section of ^{12}N on a Si target at an energy of about 30 MeV/u at NSCL [5]. The results showed that ^{12}N has a somewhat larger σ_R than their more tightly bound proton-rich neighbors. But the difference is so small that ^{12}N is a weaker halo candidate than ^{8}B. Our previous experimental results also showed that ^{12}N is a proton halo nuclei [6]. Although several experiments have been dedicated to ^{12}N, the experimental results for ^{12}N are not consistent. In order to understand the details of the halo structure of ^{12}N, the experiment of ^{12}N was performed at RIBLL [7, 8].

We report here on the total reaction cross section of ^{12}N at 34.9 MeV/u and ^{12}B at 54.4 MeV/u on a Si target at RIBLL. The nuclear matter distribution as well as their rms radii were deduced from the present experimental data together with the high energy experimental data through the Glauber model analysis.

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2 Experimental setup and detection methods

The experiment was carried out at RIBLL. The $^{14}N^{7+}$ primary beam of 78.6 MeV/u was accelerated by the Heavy Ion Research Facility of Lanzhou (HIRFL). The typical beam intensity was ~20 nA on the production target. A production target of Be with 3123 μm thickness was installed at the entrance of RIBLL (T0). We produced ^{12}N and ^{12}B by the projectile fragmentation process at the production target. The momentum acceptance of RIBLL was controlled by the slit at C1, which was set to ±1%. A wedge-shaped A1 degrader (thickness of 1937 μm at the central position) was installed at C1 for an energy-loss analysis of the secondary beam separation.

At T2 one plastic scintillator [9] with 50 μm thickness, one silicon detector (1000 μm in thickness, both as a reaction target and a ΔE detector), 2 PPACs (of 100 mm×100 mm effective size) and one telescope detector were placed respectively. The telescope detector consists of 2 silicon semiconductor detectors and one CsI(Tl) stopping detector. Both semiconductors had a thickness of 325 μm and an effective area of 45 mm×45 mm. The CsI(Tl) had a thickness of 10 mm and an effective area 70 mm×70 mm. Fig. 1 shows the schematic view of the experiment setup at T2.

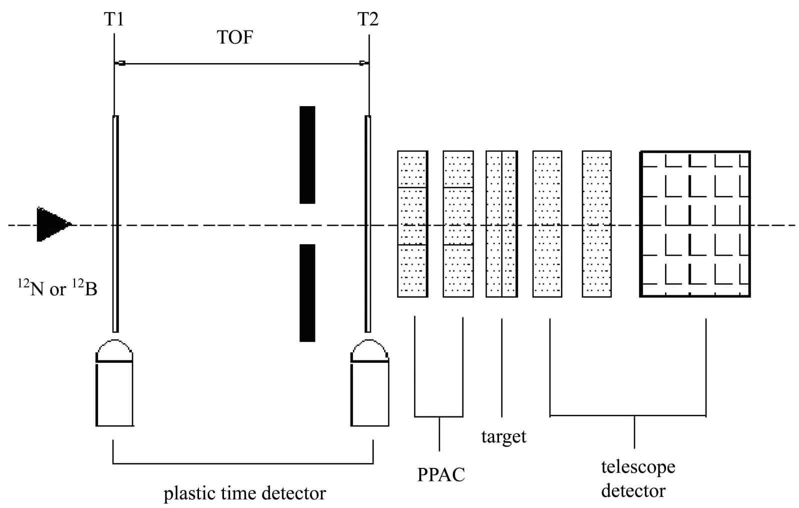

Fig. 1. Schematic view of the detection setup.

The plastic scintillator at T1 served as a start signal for the TOF and the one at T2 gave a stop signal for the TOF. Thus, the setup provided a complete particle identification before the reaction target by the TOF-ΔE method. An additional PPAC was installed at C2 to check the beam positions at C2.

The incoming ^{12}N and ^{12}B particles passing through the silicon detectors were stopped by the CsI(Tl) detector. The energy resolution of the silicon detectors was better than 1%.

3 Data analysis

The transmission method, also called the beam attenuation method, is independent of theoretical models. The total reaction cross section is expressed as

$$\sigma_{\rm R}=\frac{1}{N_{\rm t}}\ln\left(\frac{N_{\rm in}}{N_{\rm out}}\right), \qquad (1)$$

where $N_{\rm in}$ is the number of upstream particles, $N_{\rm out}$ is the number of downstream particles and $N_{\rm t}$ is the number of target nuclei in the square unit. $\sigma_{\rm R}$ at intermediate energies are quite indispensable to deduce the effective matter density distributions based on its energy dependence [10]. The total reaction cross section can be obtained by the accurate measurement of the incoming and outgoing number of ^{12}N and ^{12}B particles before and after the reaction target. The ΔE-TOF spectrum of the incoming particles is shown in Fig. 2(a), in which ^{12}N can be clearly selected and the number $N_{\rm in}$ can be obtained. The obtained total energy spectra of ^{12}N after the target is shown in Fig. 2(b). The events left to the fitted elastic peak (drawing by dotted line) are counted as reactions. The experimental results are shown in Table 1. The errors include systematic errors, statistical errors and errors from the way to select the outgoing particles.

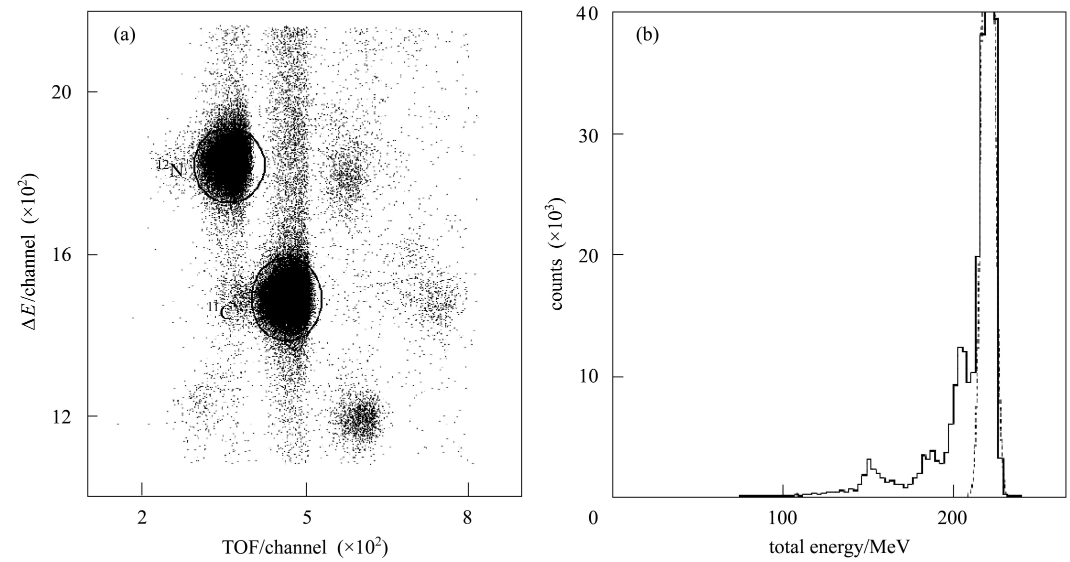

Fig. 2. (a) ΔE-TOF spectrum for the incoming particles. (b) Total energy spectra of ^{12}N after the target. The events left to the dotted line (peak obtained by Gaussian fit) are counted as reaction events.

Table 1. Results for $\sigma_{\rm R}$ of ^{12}N and ^{12}B.

nucleus	target	energy/(MeV/u)	$\sigma_{\rm R}$ or $\sigma_{\rm I}$/mb	Ref.
^{12}N	Si	34.9	1760±30	this work
		24.7	1840±50	[5]
		22.7	1770±50	[5]
		29.25	1850±50	[5]
^{12}B	C	670	889±27	[4]
		720	856±55	[4]
	Si	54.4	1490±40	this work
		25.6	1680±420	[6]
	C	790	866±7	[2]

The theoretical calculation was carried out by the so-called modified Glauber model [11–13]. It can be used to extract the nuclear density distribution by fitting the experimental results. With the input density distribution of the projectile and target, the reaction cross section can be obtained after the multi-dimensional numerical integration. The input of the model includes the matter distribution of the projectile and the target. The rms radius is defined by

$$\langle r^2\rangle^{1/2}=\frac{\left(4\pi\int\rho(r)r^4{\rm d}r\right)^{1/2}}{A^{1/2}}\ . \qquad (2)$$

We adopt a Gaussian-Gaussian distribution [14] for ^{11}C, ^{12}N and ^{12}B. By fitting the experimental data at high and medium energies the proton and neutron distributions are obtained and shown in Fig. 3. The rms. radii of ^{11}C, ^{12}N and ^{12}B are 2.15 fm, 2.41 fm and 2.33 fm.

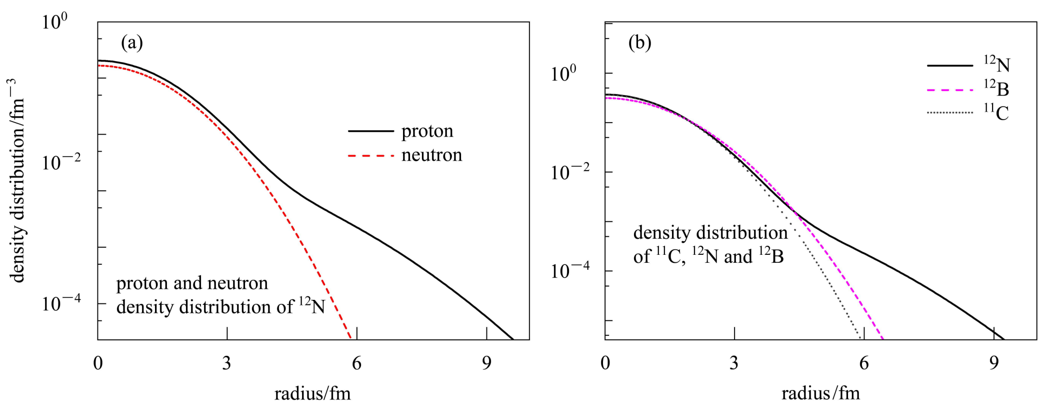

Fig. 3. (a) Neutron and proton density distributions for ^{12}N; (b) Density distribution of ^{11}C, ^{12}B and ^{12}N.

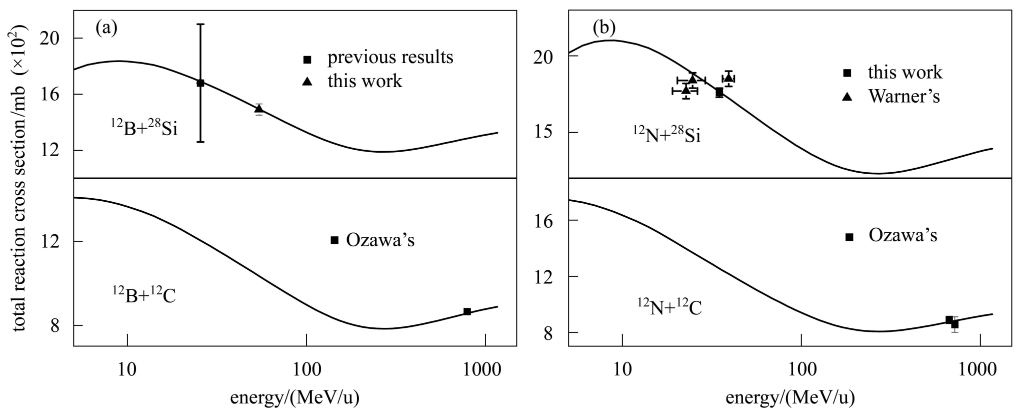

Fig. 4. Measured total reaction cross sections (dots) of ^{12}B(a) and ^{12}N(b) as a function of the incident energy together with the prediction of the Glauber model (solid line).

The present experimental data and the data at high energies are plotted in Fig. 4 together with the Glauber model calculation. The calculation is in good agreement with the experimental data. The obtained proton matter distribution of ^{12}N is a very dispersed one. Compared with ^{11}C, ^{12}N's large density distribution shows a proton halo structure.

4 Discussion

The total reaction cross section of the mirror nuclei ^{12}N and ^{12}B on a Si target was measured at intermediate energies and analyzed by a Glauber model calculation considering also other data at high energies. The obtained ^{12}N and ^{12}B rms radii are 2.41 fm and 2.33 fm as deduced from the Gaussian-Gaussian function distribution of the matter density.

Compared with ^{11}C, the nuclear matter distribution of ^{12}N is a very dispersed one and consistent with a ^{11}C+p halo structure. The obtained rms radius is more reliable by simultaneously fitting the experimental data at different energies, compared to our previous result based on only one specific energy.

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