STUDY OF ELASTIC SCATTERING OF ^{10}B IONS ON ^{12}C NUCLEI AT THE ENERGY OF 17.5 MeV*

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Elastic scattering angular distribution was measured for the ^{10}B+^{12}C system at $E_{\mathrm{lab}} = 17.5$ MeV in the angular range of $\theta_{\mathrm{cm}} = 15^{\circ}$–$165^{\circ}$. The analysis of the experimental data was carried out in the framework of the optical model and the distorted-wave method (FRDWBA) using the FRESCO code. The optical model describes well the experimental cross sections in the region of the angles of the forward hemisphere, but it is not able to reproduce the observed rise of the cross sections at large angles. Only accounting for the exchange mechanism with a deuteron transfer allows us to describe the experiment in the full angular range. Spectroscopic amplitude has been extracted from the analysis for the $^{12}\mathrm{C} \to {}^{10}\mathrm{B} + d$ configuration.

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1. Introduction

Studies of direct nuclear reactions carried out in collisions of 1p-shell nuclei bring important information about the reaction mechanism and nuclear structure. However, the analysis of such reactions requires knowledge of optical potentials, the parameters of which are usually extracted from the description of elastic scattering using an optical model. Compared to light particles, heavy-ion scattering is characterized by a stronger Coulomb interaction and absorption. A complicating circumstance is the size of the

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impinging particle, which cannot be considered point-like, so the idea of the particle's motion in the potential field is incorrect. Due to the stronger absorption, the colliding nuclei sense the potential only in the surface region. Another complication comes from the fact that in the scattering of heavy ions, an important role can be played by exchange processes [1] associated with the transfer of clusters, which strongly affects the elastic scattering cross sections, leading to a significant increase of cross sections at large angles, inexplicable by the optical model. This effect is commonly referred to as elastic transfer. The description of such angular distributions within the optical model can lead to incorrect values of the extracted potential parameters. Therefore, when analyzing the scattering of heavy ions, it is necessary to take into account the contribution of exchange processes.

The role of the exchange mechanism in the elastic scattering of heavy ions with p, d, t, ^{3}He, α-particle and ^{6}Li transfer was previously investigated in Refs. [1–9]. It has been shown that in angular distributions at large angles, the cluster transfer process really dominates.

The elastic scattering of ^{10}B on ^{12}C nuclei was previously investigated at energies of 18 MeV [1, 9], 41.3 MeV [10] and 100 MeV [11]. At the energy of 100 MeV, measurements were carried out only in a limited range of angles (10°–40° in the center-of-mass system), where a well-defined diffraction structure was observed. The same structure was observed in the anterior hemisphere and in the recently measured angular distribution at 41.3 MeV [10], which is well-described in the optical model framework. The analysis, however, showed that this model is not able to reproduce the rise of cross sections at large angles observed in the experiment, and to reach an agreement, it was necessary to take into account the exchange mechanism with the transfer of a deuteron. As demonstrated by studies at the energy of 18 MeV [1], with the beam energy approaching the Coulomb barrier, the diffraction structure in the anterior hemisphere disappears, but at large angles, it appears again and is characterized by an increase of cross sections as a function of scattering angle. Calculations have shown that even the variation of the depth of the optical potential in a wide range is not able to explain this effect. It should be noted that no specific calculations with the assessment of the contribution of elastic deuteron transfer were carried out in Ref. [1].

The aim of this work is to study the elastic scattering of ^{10}B on ^{12}C nuclei at the beam energy of 17.5 MeV. The main task is to obtain information about the role in scattering of the elastic transfer mechanism of a deuteron cluster.

2. Experimental technique

Differential cross sections for elastic scattering of ^{10}B ions on ^{12}C nuclei at $E_{\text{lab}} = 17.5$ MeV in the range of angles 15°–165° in the center-of-mass system were measured using a ^{10}B beam from the DC-60 cyclotron at the Institute of Nuclear Physics of the Republic of Kazakhstan in Nur-Sultan. Thin films of ^{12}C with a thickness of $\sim 30\ \mu\text{g/cm}^2$ were used as targets. Charged particles produced in nuclear reactions were detected by telescope counters ΔE–E, consisting of two ORTEC silicon surface-barrier detectors with thickness of 10 microns (ΔE) and 300 microns (E). Energy spectra of the scattered particles were measured for angles from 50° to 80° in the center-of-mass system using Win_EdE program with particle identification (Fig. 1 [2]) and MAESTRO-32 [12] without their identification (Fig. 2).

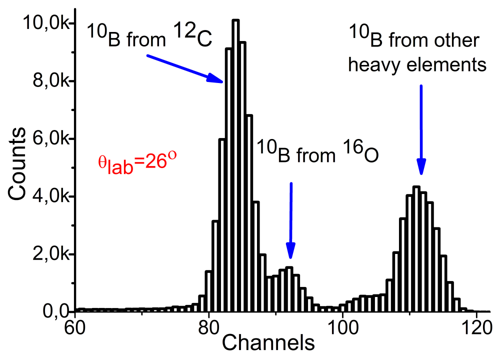

Fig. 1. Elastic scattering spectrum of ^{10}B on ^{12}C at 17.5 MeV energy and $\theta_{\text{lab}} = 26°$ with particle identification.

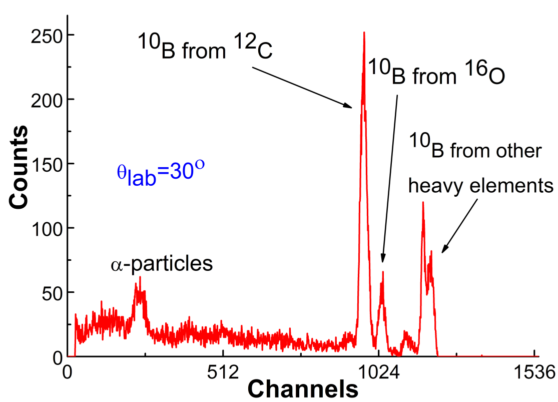

Fig. 2. Elastic scattering spectrum of ^{10}B on ^{12}C at 17.5 MeV energy and $\theta_{\text{lab}} = 30°$ acquired using MAESTRO-32.

To the right of the peak corresponding to the elastic scattering of ^{10}B on carbon, the peaks corresponding to the scattering on the impurities contained in the target are marked.

The systematic error of the measured cross sections does not exceed 10%. It includes uncertainties of the target thickness, calibration of the current integrator and of the solid angle of the spectrometer. The statistical error was at the level of 1–5% for the front hemisphere and increased at large angles, but did not exceed 10%.

3. Analysis of ^{10}B + ^{12}C scattering

At the first stage, data on elastic scattering were analyzed in the framework of the standard nuclear optical model (OM), in which the influence of inelastic channels is taken into account phenomenologically by introducing an imaginary absorbing part into the interaction potential between the colliding nuclei. In this case, the total potential of interaction with the volume absorption is as follows:

$$U(r) = -Vf(x_V) - i[Wf(x_W)] + V_{\mathrm{C}}(r)\,, \tag{1}$$

where V and W are the depths of the real and imaginary potentials, and their radial dependence is described by the Woods–Saxon form factor

$$f(x_i) = (1+\exp(x_i))^{-1}\,, \qquad x_i = (r-R_i)/a_i\,, \tag{2}$$

where a_i is the diffuseness parameter, R_i is the radius defined as: $R_i = r_i(A_{\mathrm{p}}^{1/3} + A_{\mathrm{t}}^{1/3})$, $i = V, W, C$, A_{p} and A_{t} are the mass numbers of the incoming particle and the target nucleus. V_{C}(r) is the Coulomb potential of a uniformly charged sphere of radius R_{C}. The parameter $r_{\mathrm{C}} = 1.25$ fm was used in the calculations.

To estimate the contribution of exchange effects to the elastic scattering of ^{10}B on ^{12}C nuclei, the method of distorted waves with precise consideration of the finiteness of the interaction radius (FRDWBA) was used.

The parameters of the cluster wave function of the bound 1D deuteron state in the ^{12}C core ($^{10}\mathrm{B}+d$) were taken exactly the same as in Ref. [10].

The differential cross sections, taking into account the exchange mechanism, were calculated as

$$\mathrm{d}\sigma/\mathrm{d}\Omega = |f_{\mathrm{el}}(\theta) + \mathrm{SA} f_{\mathrm{tr}}(\pi-\theta)|^2\,, \tag{3}$$

where SA is the spectroscopic amplitude, $f_{\mathrm{el}}(\theta)$ is the elastic scattering amplitude, and $f_{\mathrm{tr}}(\pi-\theta)$ is the elastic deuteron transfer amplitude.

4. Discussion of results

Calculations using both the optical model and the distorted-wave method (FRDWBA) were carried out using the FRESCO program [13]. Table I presents the optical model potential parameters that optimally describe the data. They differ slightly from the parameters obtained in Ref. [1] for elastic scattering at the energy of 18 MeV.

TABLE I

The optimal potential parameters for the system $^{10}\mathrm{B} + ^{12}\mathrm{C}$ at $E_{\mathrm{lab}} = 17.5$ MeV.

Model/Ref.	V [MeV]	r_V [fm]	a_V [fm]	W [MeV]	r_W [fm]	a_W [fm]
OM	110.0	1.125	0.57	8.5	1.3	0.22
OM [1]	100.0	1.15	0.5	10	1.3	0.22
OM+FRDWBA	110.0	1.125	0.57	8.5	1.3	0.22

Comparison of calculated cross sections with experimental data is shown in Fig. 3. An agreement with the experiment can be achieved only by taking into account the exchange mechanism with the transfer of a deuteron. When calculating the cross sections in this case, the value of the spectroscopic amplitude (SA) for the configuration $d + ^{10}\mathrm{B}$ was a free parameter and was determined from the comparison of the calculated cross sections with the experimental ones. The best description of the experimental data is achieved at SA = 1.78. This value is slightly different from the result (SA = 1.375)

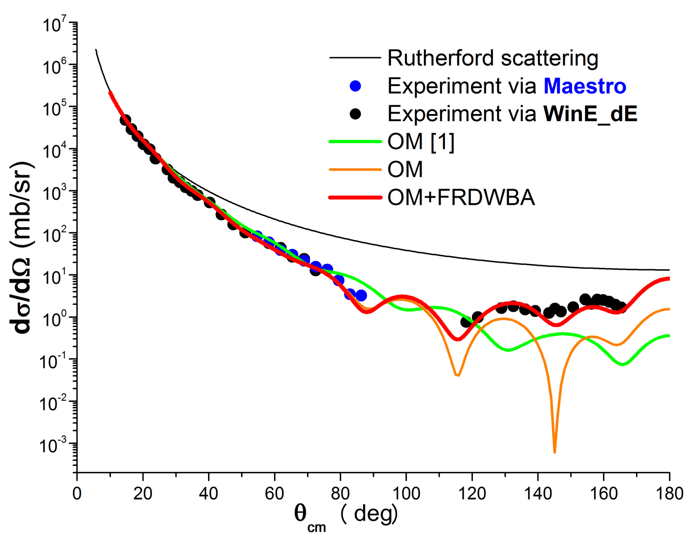

Fig. 3. Angular distribution of elastic scattering of $^{10}\mathrm{B}$ on $^{12}\mathrm{C}$ at $E_{\mathrm{lab}} = 17.5$ MeV.

obtained in a previous study of scattering at the energy of 41.3 MeV [10], while it is in agreement with the theoretical value of SA $= 1.78$ calculated in the framework of the translational invariant shell model [14].

5. Conclusion

Elastic scattering of ^{10}B ions on ^{12}C nuclei was studied at 17.5 MeV energy in a wide range of angles. The analysis of the measured angular distribution was carried out using the FRESCO program. As a result of the analysis, the value of the spectroscopic amplitude SA $= 1.78$ for the configuration $^{12}\mathrm{C} \to {}^{10}\mathrm{B} + d$ was extracted, which is in good agreement with the results of the study of elastic scattering at an energy of 41.3 MeV [10] and with calculations in the framework of the translational invariant shell model [14]. The extracted value indicates a high degree of clustering in ^{12}C with a structure of $^{10}\mathrm{B}+d$.

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