STUDY OF ELASTIC SCATTERING OF ^{15}N IONS BY ^{11}B NUCLEI AT LOW ENERGIES*

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Received 15 November 2022, accepted 22 November 2022, published online 26 January 2023

The experimental cross sections for elastic scattering of heavy ^{15}N ions on a target of ^{11}B isotopes were measured using an extracted beam at the DC-60 cyclotron at the Institute of Nuclear Physics (Astana, Kazakhstan). The beam energy of accelerated heavy ions was $E_{\rm lab} = 18.75$ MeV. The angular distribution of scattered ions was in the range from 10 to 50 degrees in the laboratory coordinate system. This paper provides a detailed description of the experimental procedure and a brief description of the equipment. The results of the study are experimental data on the interaction ^{11}B(^{15}N, ^{15}N)^{11}B and theoretical calculations for the process of elastic scattering ^{15}N + ^{11}B. Theoretical calculations were performed within the framework of an optical model. The Woods–Saxon optical potential was used to analyze the experimental results of elastic scattering. As a result, good agreement was achieved between experimental data and theoretical predictions. The results of calculations within the framework of the theoretical model will be used for further analysis of experimental data on inelastic scattering of ^{15}N by ^{11}B.

DOI:10.5506/APhysPolBSupp.16.2-A17

1. Introduction

Works aimed at studying the processes of elastic and inelastic interaction of atomic nuclei with each other attract special interest in each study [1–3]. Since a lot of information about the structure and properties of nuclei can be obtained from the results of scattering. The accuracy of the obtained information about the collision of nuclei directly depends on the correctness and accuracy of the parameters of the interaction potentials. In recent years,

* Presented at the IV International Scientific Forum *Nuclear Science and Technologies*, Almaty, Kazakhstan, 26–30 September, 2022.

more and more systematic studies of the energy dependences of nuclear reactions have been carried out [4–6]. Of particular interest are the nuclear scatterings of carbon, C, nitrogen, N, and oxygen, O, isotopes. The study of the elastic interaction of heavy ions on the nuclei of the $1p$ shell at energies near the Coulomb barrier is of particular interest from the point of view of establishing reliable values of the parameters of the interaction potentials of heavy ions [7] for astrophysical applications.

However, studies of nuclear systems involving ^{15}N are very rare due to the difficulties of accelerating ^{15}N ions. For example, for the ^{15}N+^{11}B system, there is only the work of Rudchik *et al.* [8]. This fact further increases the interest in the study of this system.

Previously, we studied collisions of ^{15}N ions with the ^{16}O nucleus at $E_{\rm cm} = 11.59$ MeV [9] and with ^{10,11}B nuclei at an energy of 43 MeV [10]. In these papers, a significant increase in cross sections at reverse angles was interpreted as transfers of protons and α-clusters. Thus, the reactions of $1p$-shell nuclei with ^{15}N are a good example for studying transport mechanisms, especially at low energies close to the energy of the Coulomb barrier.

In this work, we obtained the angular distributions of elastic scattering of ^{15}N by ^{11}B at an energy of 18.75 MeV in the angle range of 23°–160° in the center-of-mass system. Registration and identification of particles was carried out on a DC-60 cyclotron (Astana) using silicon surface barrier detectors ΔE (8 microns) and E (300 microns) from ORTEC. ^{11}B films with a thickness of about 50 μg/cm^2 were used as targets. The data were analyzed within the framework of an optical model (OM) using the Fresco code [11], as a result of which the optimal potential parameters were obtained. This work is part of the cycle of our study of the system of ^{15}N nuclei on light nuclei at near-barrier energies.

2. Experimental technique

In this work, we obtained the angular distributions of elastic scattering of ^{15}N by ^{11}B at $E_{\rm lab} = 18.75$ MeV in the range of angles in the center-of-mass system of 23°–160°. Particle detection was carried out at the branch of the Institute of Nuclear Physics of the Republic of Kazakhstan (Astana) at the DC-60 cyclotron using silicon surface-barrier detectors dE and E, 8 and 300 microns thick, respectively. ^{11}B films with a thickness of $\sim$ 50 μg/cm^2 were used as targets. The elastic scattering spectra were detected using the ΔE–E crate of the technique. A typical example of the identification of scattering spectra by the Win_EdE program is shown in figure 1. A separate locus of ^{15}N scattering on various elements is shown in figure 2. The spectrum shows a good separation of reaction products by charge (Z = 2–8). More detailed information about the experimental setup and the scattering chamber used in the experiment can be found in earlier works [12–14].

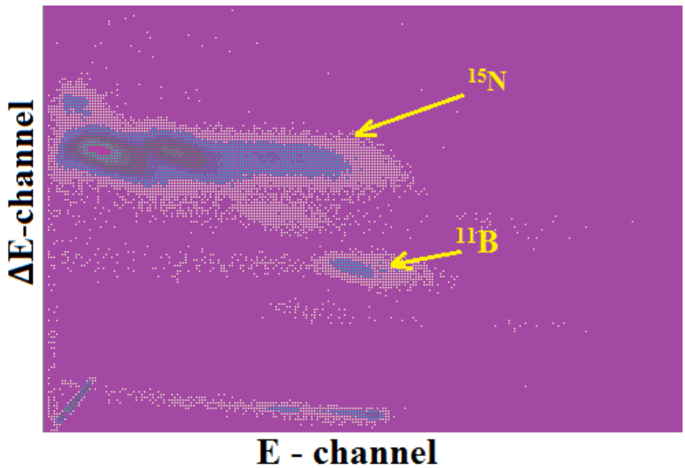

Fig. 1. A typical two-dimensional loci of elastically scattered ^{15}N ions on ^{11}B nuclei at energy $E_{\rm lab}$ = 18.75 MeV. The figure shows the loci of α-particles, boron, and nitrogen *etc.*

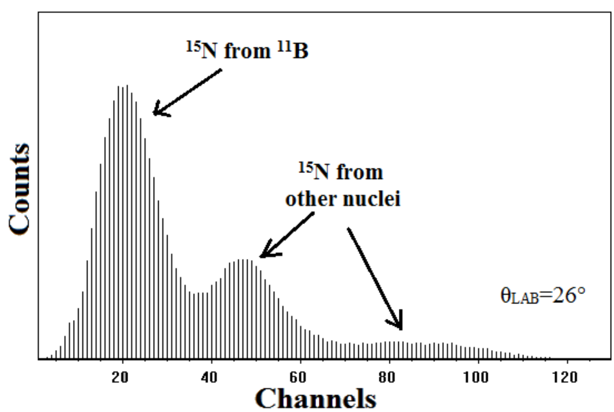

Fig. 2. Typical energy spectrum measured at an angle of 26° when ^{15}N collides with ^{11}B target nuclei without particle identification. To the right of the peak corresponding to the elastic scattering ^{15}N on the boron, the peaks corresponding to the scattering on the impurities contained in the target are marked.

The systematic error of the measured cross sections does not exceed 10%. It was determined by errors in determining the target thickness, calibration of the current integrator, and inaccuracy in determining the value of the solid angle of the spectrometer. The statistical error was at the level of 1–5% for measurements in the region of the angles of the anterior hemisphere and increased at large angles, but never exceeded 10%.

3. Theoretical description of elastic scattering of the ^{15}N + ^{11}B system

In the first stage, data on elastic scattering were analyzed in the framework of the standard optical model (OM) of the nucleus, 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

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

where a_i is the diffusivity, 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. $V_{\mathrm{C}}(r)$ 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.

The parameters of optical potentials (OPs) were chosen in such a way as to achieve the best agreement between the theoretical and experimental angular distributions. Theoretical calculations were performed using the Fresco program. Automatic search for the parameters of optical potentials was carried out by minimizing the value of χ^2/N.

4. Discussion of results

In this work, differential cross sections for elastic scattering of ^{15}N ions on ^{11}B nuclei were calculated within the framework of OM. Table 1 shows the OPs obtained by this model. As can be seen from figure 3, all the obtained results of the OM are in good agreement with the experimental data.

Table 1. Optimum potential parameters for the $^{15}\mathrm{N} + {}^{11}\mathrm{B}$ system at an energy of 18.75 MeV; the Coulomb radius parameter r_C was fixed at 1.25 fm.

Model	V [MeV]	r_V [fm]	a_V [fm]	W [MeV]	r_W [fm]	a_W [fm]	χ^2/N
OM	132.798	0.746	0.3	10.524	1.329	0.673	4.75

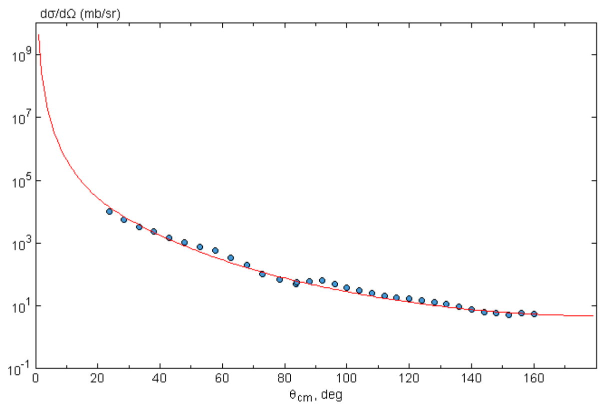

Fig. 3. Data on the differential cross section of elastic scattering of ^{15}N by ^{11}B at $E_\mathrm{lab} = 18.75$ MeV.

5. Conclusion

In this paper, we present new data on the elastic scattering of ^{15}N ions by ^{11}B at 18.75 MeV over a wide range of angles. Registration and identification of particles was carried out on a DC-60 cyclotron (Astana) using silicon surface barrier detectors dE (8 microns) and E (300 microns) from ORTEC. ^{11}B films with a thickness of about 50 μg/cm^2 were used as targets. The data were analyzed within the framework of an optical model (OM) using the Fresco code, which resulted in the optimal potential parameters. The data were analyzed within the framework of optical model methods.

This research is funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (grant No. AP14871692).

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