INVESTIGATION OF SCATTERING OF DEUTERONS ON ^{10}B NUCLEUS AT 14.5 MeV*

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The differential cross sections of elastic and inelastic (1^+, 0.718 MeV) scattering of deuterons on the ^{10}B target were measured in the angular range of 20°–160° in the center-of-mass system at an energy of 14.5 MeV. The analysis of the measured angular distributions was carried out by the method of coupled channels using the Fresco program. Two sets of optical potentials have been established that correctly describe elastic scattering data at energies of 11.8, 14.5, and 28 MeV. The value of the quadrupole deformation parameter $\beta_2 = 0.72 \pm 0.1$ is extracted from the comparison of the calculated cross sections of inelastic scattering with experimental data. Within the error limits, the extracted β_2 value agrees well with the results obtained from the analysis of protons, deuterons, and ^{3}He scattered from the ^{10}B target.

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1. Introduction

The isotopes of ^{10,11}B nuclei are illustrative examples for the manifestation of both shell effects and single-particle levels in light nuclei. Usually, the entire spectrum of ^{11}B states up to excitation energies of ~ 7 MeV is fairly correctly reproduced using various versions of the nuclear shell model. At the same time, the one-particle shell model is mainly used to describe the levels of the ^{10}B nucleus.

Direct nuclear reactions proceeding with the pickup of one nucleon are widely used to obtain spectroscopic information about the hole states of nuclei. In these studies, reactions induced by light projectiles (p, d, and

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^{3}He) play an important role due to their simple and well-known structure, these include reactions such as (p, d), (d, t), and (^{3}He,α). Despite a long history of research, the (d, t) reaction on the ^{10}B nucleus still remains poorly studied. There is only one work done in the 1960s at the deuteron energy of 11.8 MeV [1]. The extracted values of the spectroscopic factors for the $^{10}\mathrm{B} \to {}^9\mathrm{B} + n$ configuration turned out to be somewhat less than the predicted theoretical values obtained on the basis of the shell model with the intermediate coupling [2]. Note that the ^{10}B nucleus in the middle of the p-shell has a high nuclear quadrupole moment ($Q = +84.72$ mb) [3]. Therefore, it is necessary to take into account the collective nature of the 0.718 MeV (1^+) state of the ^{10}B nucleus. This is supported by the results of studying the $^{11}\mathrm{B}(\alpha, t)^{12}\mathrm{C}$ reaction [4]. The same result was obtained in the study of the $^{11}\mathrm{B}$ $(d, t)^{10}\mathrm{B}$ reaction, taking into account the deformation of the ^{11}B and ^{10}B nuclei [5].

Within the framework of the present study, it is planned to investigate the elastic and inelastic scattering of deuterons by the ^{10}B nucleus at an energy of 14.5 MeV in order to obtain information for clarifying the role of the direct neutron pickup mechanism using the coupled channels (CC) method, taking into account the deformation of the ^{10}B nucleus and reanalyzing the previously obtained data at the deuteron energy of 11.8 and 28 MeV.

2. Experimental setup

The experimental measurements were performed using a 14.5-MeV deuteron beam extracted from the U-150M isochronous cyclotron at the Institute of Nuclear Physics, Almaty, Kazakhstan incident on a self-supporting boron target of the thickness of 0.250 mg/cm^2 ($\sim 90\%$ enrichment in ^{10}B). Products of the nuclear reaction were registered by a counter telescope consisting of two silicon detectors: thin (ΔE) with thicknesses of 15–50 μm, and thick (E) with thicknesses of 1–2 mm. The separation of deuterons from other types of charged particles was carried out by a two-dimensional analysis system (ΔE–E) using electronics in the CAMAC standard and a processing program implemented on a personal computer. The experimental technique is described in detail in our recent paper [5]. The measured differential cross sections of elastic and inelastic (1^+, 0.718 MeV) scattering of deuterons on the ^{10}B target were measured in the angular range of 20°–160° in the center-of-mass system at an energy of 14.5 MeV as shown in Figs. 1 and 2.

3. Theoretical analysis of experimental data

The optical model of a nucleus (OM) [6] is used for the theoretical calculation of differential elastic scattering cross sections. The parameters of the phenomenological optical potential (OP) are found from a comparison of the calculation results with experimental data. In OM studies, it has been customary to use a complex central potential of the Woods–Saxon (WS) shape and its derivatives, a spin-orbit term, and a Coulomb term. Hence, the optical potential has been written as

$$V(r) = VC(r) - V_0 f(r, r_V, a_V) - i4a_D W_D \frac{\mathrm{d}}{\mathrm{d}r} f(r, r_D, a_D) + V_{\mathrm{SO}} \left(\frac{\hbar}{m_\pi C}\right)^2 (L\sigma)\, \frac{1}{r}\frac{\mathrm{d}}{\mathrm{d}r} f(r, r_{\mathrm{SO}}, a_{\mathrm{SO}}), \tag{1}$$

where the WS form factor is given by

$$f(r, r_i, a_i) = \left[1 + \exp\left(\frac{r - r_i A_{1/3}}{a_i}\right)\right]^{-1}, \qquad (i = V, D, \mathrm{SO}) \tag{2}$$

and A is the target mass number. The Coulomb term is taken as the potential for a uniformly charged sphere of radius $R_{\mathrm{C}} = 1.3\,A^{1/3}$. Taking into account the features of the interaction of deuteron with nuclei, the surface type of absorption W_D was used as an imaginary potential, and the contribution of the spin-orbit potential V_{SO} to the scattering process was also taken into account.

It is well known that the parameters of optical potentials have discrete and continuous ambiguities. Therefore, to eliminate the discrete ambiguity of the real part of the potential, its dependence on energy is often used. For this purpose, global systematics of the OP parameters for the $d+{}^{10}\mathrm{B}$ system was carried out in a wide energy range using previously measured data at energies of 11.8 [1] and 28 MeV [7] in addition to our measured data at 14.5 MeV. Based on this, first of all, the experimental data were analyzed at an energy of 28 MeV [7]. As starting parameters, we used the OP parameters established in Refs. [1, 8, 9]. The search for the OP parameters was carried out by fitting the calculated angular distributions to the experimental data using the Fresco code [10] upgraded with the χ^2 minimization Sfresco search code. To eliminate discrete ambiguity in determining the optical parameters, the radii of the real (r_V) and imaginary (r_W) parts of the potentials were fixed. The experimental data were adjusted to theoretical calculations by varying the 4 remaining parameters of the OP (V_0, W_D — depths of the real and imaginary parts of the potential; a_V and a_D — diffuseness of the real and imaginary parts of the potential, respectively). The fit of the calculated cross sections to the experimental data was performed in the fullest possible angular range. The two sets of optimal optical potentials established in this approach (A and B) are listed in Table 1.

Table 1. Optimal OP parameters for the $d + {}^{10}$B system.

E [MeV]	Set	V_0 [MeV]	r_V [fm]	a_V [fm]	W_D [MeV]	r_D [fm]	a_D [fm]	V_{SO} [MeV]	r_{SO} [fm]	a_{SO} [fm]
11.8	A	118.0	0.863	0.947	5.25	1.59	0.757	6.0	0.863	0.916
	B	84.6	1.17	0.835	4.61	1.325	0.955	6.62	1.07	0.66
14.5	A	119.1	0.863	1.01	6.98	1.825	0.586	6.0	0.863	0.916
	B	86.06	1.17	0.889	5.61	1.325	0.886	6.0	1.07	0.66
28.0	A	100.2	0.863	0.916	10.32	1.59	0.716	6.0	0.863	0.916
	B	72.94	1.17	0.863	14.01	1.325	0.625	6.0	1.07	0.66

The comparison between the experimental angular distribution for the $d + {}^{10}$B at $E = 11.8$, 14.5, and 28.0 MeV and the OM calculations is shown in Fig. 1. Both sets of OPs are identical in qualitatively reproducing the behaviour of the available experimental angular distributions at all energies. The difference is for the description of the angular distributions at an energy of 28 MeV. At this energy, the set A of potentials gives a sharp increase in cross sections at reverse angles, which is not characteristic of the potential scattering mechanism.

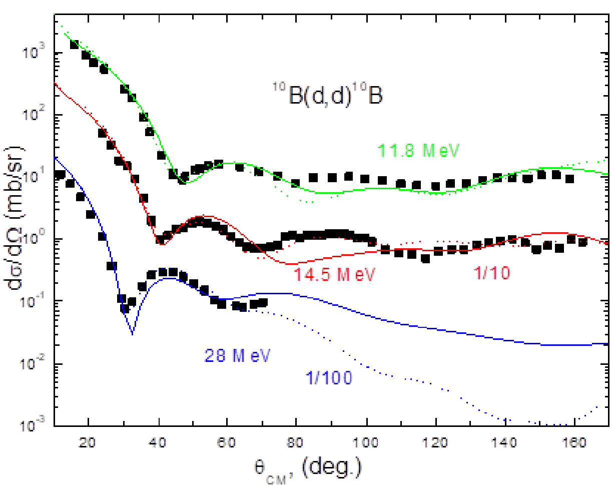

Fig. 1. Angular distributions of elastic scattering of deuterons on ^{10}B nuclei at the energies of 11.8, 14.5, and 28 MeV. Calculations using potential set (A) are represented by solid curves, while dotted curves are for calculations using set (B).

The calculations of the elastic and inelastic scattering were performed by the coupled channel method in the *prior*-representation of the method of distorted waves with a finite-interaction radius using the Fresco code. In the theoretical calculations, we took into account the fact that the ^{10}B nucleus has a large quadrupole deformation, and both the ground- and the first-excited (0.718 MeV, 1^+) states are connected by a strong quadrupole (E_2) transition. Figure 2 shows the results of calculations of elastic and inelastic scattering at energies of 11.8 and 14.5 MeV using the OP of set A. The value of the quadrupole deformation parameter $\beta_2 = 0.72 \pm 0.1$ was extracted from a comparison of the calculated inelastic scattering cross sections with the experimental ones. Within the limits of errors, it agrees quite well with the results of the analysis obtained from the scattering of protons, deuterons, and ^{3}He from the ^{10}B target.

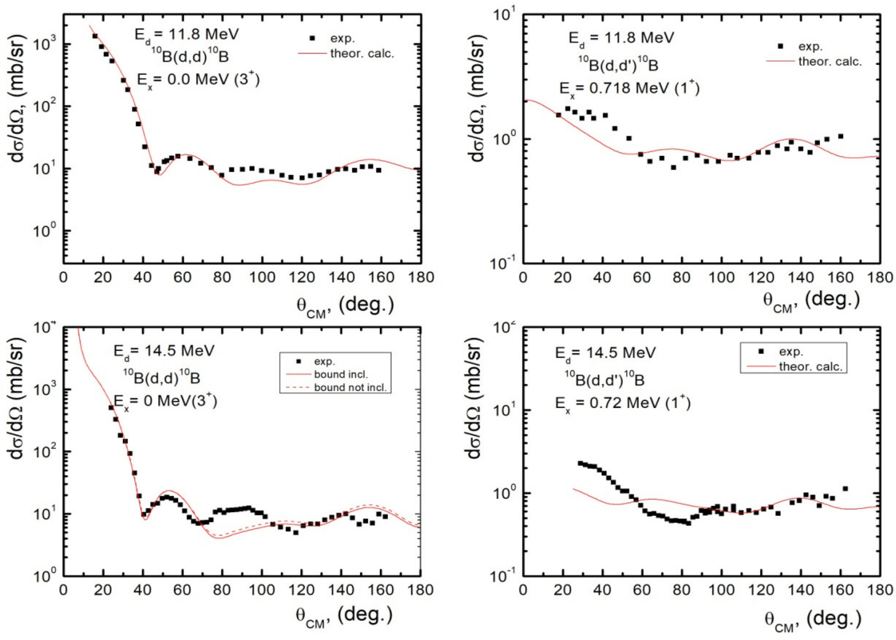

Fig. 2. Angular distributions of elastic and inelastic scattering of deuterons on ^{10}B nuclei at the energies of 11.8 and 14.5 MeV. Statistical errors (no more than 10%), which do not exceed the size of the symbols.

As can be seen from Figs. 1 and 2, only the angular distribution of elastic scattering has a well-defined diffraction structure. In inelastic scattering, it manifests itself much weaker. In addition, in contrast to the scattering of deuterons by ^{11}B nuclei [5], in the angular distributions of scattered deuterons by ^{10}B nuclei, a significant rise in the cross section at reverse angles is observed.

4. Conclusion

Angular distribution for deuterons elastically scattered from the ^{10}B target was measured at the energy of 14.5 MeV. In addition to the elastic data, the inelastic angular distribution for the (1^+, 0.718 MeV) ^{10}B excited state was also estimated. The experimental measurements were performed in the angular range of 20°–160° in the center-of-mass system. In addition to our data at 14.5 MeV, the previously measured angular distributions for the $d + {}^{10}$B system at energies of 11.8 and 28 MeV are also investigated using the CC method by taking into account the coupling to the (1^+, 0.718 MeV) ^{10}B state in appreciation of the high quadrupole moment ($Q = +84.72$ mb) of the ^{10}B nucleus. Two sets of optical potentials have been established that reasonably describe the elastic scattering data at energies of 11.8, 14.5, and 28 MeV. The value of the quadrupole deformation parameter $\beta_2 = 0.72 \pm 0.1$ was extracted from the best agreement between the experimental inelastic data and the theoretical CC calculations. The extracted β_2 value agrees well with previously reported ones obtained from the scattering of protons, deuterons, and ^{3}He on the ^{10}B target.

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