QUADRUPOLE DEFORMATION OF ^{11}B ($3/2^-$, 5.02 MeV) EXCITED STATE FROM ^{11}B + ^{12}C SCATTERING*

S.Yu. Mezhevych[a,b] and K. Rusek[a]

[a]Andrzej Sołtan Institute for Nuclear Studies, Hoża 69, 00-681 Warsaw, Poland
[b]Institute for Nuclear Research, Prospect Nauki 47, 03680 Kiev, Ukraine

(Received December 2, 2002)

Experimental data for elastic and inelastic scattering of ^{11}B ions by ^{12}C nuclei measured recently at the Warsaw Cyclotron were analyzed by means of the coupled-reaction-channel method. Rotational model for the low-lying states in ^{11}B and ^{12}C was assumed. The deformation lengths for the ^{11}B and ^{12}C ground states as well as for the ^{11}B $3/2^-$ excited state ($E_x = 5.02$ MeV) were extracted from the analysis. Contrary to the theoretical predictions the deformation length of the ^{11}B $3/2^-$ excited state was found to be large, close to that of the ground state.

PACS numbers: 24.10.Eq, 24.50.+g, 25.70.Bc, 27.20.+n

Structure of the low-lying levels of ^{11}B can be explained either by the rotational model [1] or by $\alpha + {}^7$Li cluster model [2]. The first approach can be justified by the large spectroscopic quadrupole moment, $Q_S = +40.65$ mb [3], of the ^{11}B ground state. Detailed calculations presented in Ref. [1] have shown that the ground state of ^{11}B and $5/2^-$ excited state at excitation energy of about 4.45 MeV belong to the $K = 3/2^-$ rotational band. The $1/2^-$ first excited state is the head of $K = 1/2^-$ rotational band while the $3/2^-$ excited state at $E_x = 5.02$ MeV forms another $K = 1/2^-$ rotational band. Deformations of the $K = 3/2^-$ and $K = 1/2^-$ rotational bands were found in those calculations to be almost equal while the deformation of the second $K = 1/2^-$ band is much smaller and of opposite sign.

Recently, experimental data for elastic and inelastic scattering of ^{11}B from ^{12}C at $E_{LAB} = 49$ MeV were obtained [4]. This opened a possibility to study the deformation of ^{11}B in its ground and excited states by means of

* Presented at the XXXVII Zakopane School of Physics "Trends in Nuclear Physics", Zakopane, Poland, September 3–10, 2002.

extensive coupled-reaction-channel (CRC) calculations. The calculations were performed using the computer code FRESCO, version FRXX-v9h [5]. The analyzed data set comprised the four angular distributions of the differential cross section for elastic scattering as well as for inelastic scattering to the $1/2^-$ and $3/2^-$ excited states of ^{11}B. Inelastic scattering to the $5/2^-$ excited state of ^{11}B and to the 2^+ excited state of ^{12}C could not be distinguished experimentally.

In the analysis the optical model potential was taken in the standard complex form $V(r) + iW(r)$. Its real part was generated by means of the computer code DFPOT [6] from the densities of the both interacting nuclei using the double folding method

$$V(r) = \int\int \rho_1(r_1)\rho_2(r_2)v_{12}(r)dr_1dr_2\,, \tag{1}$$

where $\rho_1(r_1)$, $\rho_2(r_2)$ are mater densities of ^{11}B and ^{12}C, and $v_{12}(r)$ is the nucleon–nucleon interaction, which was taken in the standard M3Y form. Distributions of the neutrons in ^{11}B and ^{12}C were assumed to be the same as the distributions of the protons. Charge densities of ^{11}B and ^{12}C nuclei were calculated according to the modified harmonic-oscillator model [7] with the parameters $a = 1.69$, $\alpha = 0.811$ for ^{11}B and $a = 1.635$, $\alpha = 1.403$ for ^{12}C. The imaginary part $W(r)$ of the potential was assumed to be of the Woods–Saxon form.

The analysis was performed in the following way. First, the forward angle elastic scattering data were fitted by optical model calculations with the four free parameters: N — normalization factor of the real part $V(r)$ and the three parameters of the imaginary part — W, r_w and a_w. The following values of the parameters were found: $N = 1.0$, $W = 7.5$ MeV, $r_w = 1.25$ fm and $a_w = 0.67$ fm. Next, couplings to the three lowest excited states of ^{11}B, *i.e.* $1/2^-(E_x = 2.12\,\text{MeV})$, $5/2^-(E_x = 4.44\,\text{MeV})$ and $3/2^-(E_x = 5.02\,\text{MeV})$, were included. All the states of ^{11}B were treated as the rotational states according to the predictions of El-Batanoni and Kresnin [1]. The deformation lengths were varied in the calculations in order to obtain the best possible fit to the experimental data.

As a next step the coupling to the excited state $2^+(E_x = 4.45$ MeV) of ^{12}C nucleus was included in the coupling scheme. Here the two states of ^{12}C were treated as members of $K = 0$ rotational band. Coupling interactions were calculated to all orders in the deformations [8].

Finally, the process of one-proton transfer, experimentally indistinguishable from the scattering, was added for each transition. Single-proton spectroscopic amplitudes for the $^{12}\text{C}_{\text{g.s.,exc.s.}} = {}^{11}\text{B}_{\text{g.s.,exc.s.}} + p$ systems were deduced from the fit to the experimental data at backward angles.

The calculations reproduced well all the four experimental angular distributions. Two examples are shown in Figs. 1 and 2. In Fig. 1 the solid curve shows results of the full CRC calculations. When the proton transfer was omitted, the calculations could not reproduce the values of the differential cross section at backward scattering angles as it is shown by the short-dashed curve.

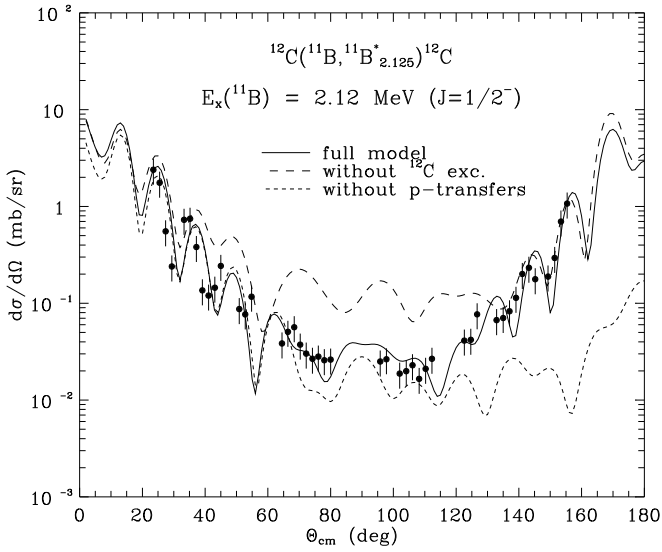

Fig. 1. Channel coupling effects for inelastic scattering of $^{11}B + {}^{12}C$. See text for details.

The influence of the target excitation to its first excited state was found in the course of the calculations to play a very important role. CRC calculations with the target excitation not included are plotted by the dashed curve in Fig. 1.

Spectroscopic amplitudes for $^{12}C_{g.s.} = {}^{11}B_{g.s.,exc.s.} + p$ found from fitting the experimental data at backward angles were close to those predicted by Rudchik *et al.*, [4]. The largest difference was observed for the projection $^{12}C_{g.s.} = {}^{11}B^{*}_{3/2-} + p$.

The deformation lengths $\delta_2 = 1.0\,\mathrm{fm}$ for the $^{11}B_{g.s.}$ as well as $\delta_2 = -0.9\,\mathrm{fm}$ for the $^{12}C_{g.s.}$ were in good agreement with results of the previous analysis [4]. In order to test the sensitivity of the calculations to the deformation of ^{11}B nucleus in the $3/2^-(E_x = 5.02$ MeV) excited state CRC calculations were performed with the deformation length of this state varied from 0.6 fm to 1.2 fm. The results are plotted in Fig. 2 by the short-dashed and solid curves, respectively. The best fit was obtained with $\delta_2(^{11}B^{*}_{5.02}) = 0.8$ fm.

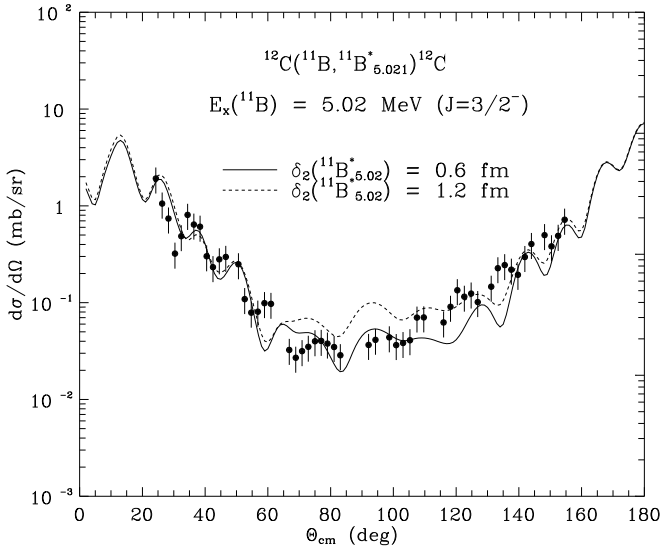

Fig. 2. Sensitivity of the CRC calculations to the quadrupole deformation of $3/2^-$ excited state of ^{11}B.

In summary, the CRC analysis of the experimental data for elastic and inelastic scattering of ^{11}B by ^{12}C at the laboratory energy of 49 MeV was performed. It was found that the excitation of the target to its first excited state has a large influence on the calculated results for the inelastic scattering. Deformation lengths for the ground states of ^{11}B and ^{12}C extracted from the calculations agreed well with those from Ref. [4]. Contrary to the theoretical predictions [1] the deformation of the ^{11}B in its $3/2^-(E_x = 5.02$ MeV) excited state was found to be very close to the deformation of the ^{11}B ground state.

REFERENCES

[1] F. El-Batanoni, A.A. Kresnin, *Nucl. Phys.* **89**, 577 (1966).
[2] A. Kabir, B. Buck, *Nucl. Phys.* **A533**, 215 (1991).
[3] F. Ajzenberg-Selove, *Nucl. Phys.* **A506**, 1 (1990).
[4] A.T. Rudchik *et al.*, *Nucl. Phys.* **A695**, 51 (2001).
[5] I.J. Thompson, *Comp. Phys. Rep.* **7**, 167 (1988).
[6] J. Cook, *Comput. Phys. Commun.* **25**, 125 (1982).
[7] H. De Vries *et al.*, *At. Dat. Nucl. Dat. Tables* **36**, 495 (1987).
[8] K. Hagino *et al.*, *Phys. Rev.* **C55**, 276 (1997).