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Nassurlla Burtebayev, Daniyar Janseitov, Zhambul Kerimkulov, et al.

Investigation of the Excited States of ^{11}B in Interactions with Alpha Particles

Nassurlla Burtebayev[1], Daniyar Janseitov[1, 2, 3, a)], Zhambul Kerimkulov[1, 4], Marzhan Nassurlla[1], Yerzhan Mukhamejanov[1], and Dilshod Alimov[1,4]

[1]*Institute of Nuclear Physics, 1 Ibragimov, 050032, Almaty, Kazakhstan*
[2]*Al Farabi Kazakh National University, 71 Al Farabi, 050040, Almaty, Kazakhstan*
[3]*Joint Institute for Nuclear Research, 6 Joliot-Curie, 141980, Dubna, Moscow region, Russia*
[4]*L.N.Gumilev Eurasian National University, 2 Satpayev, 010008, Nur-Sultan, Kazakhstan*

[a)]*Corresponding author: janseit.daniar@gmail.com*

Abstract. The elastic and inelastic scatterings of α-particles were investigated at an energy of 29 MeV with excitation of low-lying states of the ^{11}B nucleus. As a result of research we obtained new experimental data for the $\alpha + {}^{11}$B inelastic scattering one leading to the 2.12 MeV ($1/2^-$), 4.44 MeV ($5/2^-$) and 6.74 MeV ($7/2^-$) excited states of ^{11}B nucleus. In the framework of Modified diffraction model, the root mean square radii of these excited states are calculated. The theoretical calculations for the concerned excited states were performed using the coupled channel (CC) method.

INTRODUCTION

Study of elastic and inelastic scattering processes of light charged particles, such as deuterons and alpha particles, is one of the main sources of the information about the nuclear potentials, which are used to calculate the wave functions describing the relative motion of the colliding particles, as well as information about the properties of ground and low lying excited sates of nuclei. These processes take place in collisions of alpha particles at energies of tens of MeV and allow obtaining valuable information about the structural characteristics of nuclei, such as deformation parameters and nuclear radii.

Today there are few works with experimental data on elastic and inelastic alpha particles scattering by ^{11}B nuclei in moderate energy range [1, 2] and these data are poorly studied experimentally and theoretically. Therefore, this information contains very contradictory data. It also should be noted that in the very early works on studying scattering processes incident particles were emitted by natural radioactive nuclei.

Of particular interest from the point of view of studying excited states of ^{11}B nucleus, where both cluster configuration (2α+t), and the shell model structure can co-exist at the same time. Indeed, several studies have suggested that low-lying states of ^{11}B, basically have a shell structure, while the cluster structures are easily traced in the states with negative parity above or near the threshold of breakup into clusters [3].

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Since these states have large widths for α decay then this band may be formed on the basis of the cluster structures. Besides, the analogy of the cluster structure of ^{11}B nucleus with three cluster structure of ^{12}C is a fascinating challenge for the study. In particular, in [4], it was suggested that $3/2^-$ (8.56 MeV) state may have a structure consisting of three clusters as 2α+t configuration, and may be an analogue of the excited state of ^{12}C (0_+^2), which has a structure consisting of three alpha particles [5]. There are several of works, where analogs of the Hoyle state can also exist in other neighboring nuclei were predicted [6, 7].

This paper is a continuation of our previous work [8]. In this part of paper, we studied the inelastic $\alpha+^{11}B$ scattering at E(α) = 29 MeV. In the framework of the modified diffraction model (MDM) [9], the root mean square (rms) radii of the excited states of ^{11}B to ~ 7 MeV were calculated.

EXPERIMENTAL METHODS

Experimental angular distributions of elastic and inelastic scattering of alpha particles from nuclei ^{11}B were measured on the extracted beam of isochronous cyclotron U-150M at the Institute of Nuclear Physics (Almaty, Kazakhstan) at E(α)=29 MeV within angular range of 10-100 degrees in laboratory system.

In the "ΔE-E" telescope of detectors, ΔE - detector is a surface-barrier silicon detector (manufactured by ORTEC) with an active layer of thickness of 30 to 200 μm and thin inlet (~ 40 μg/cm^2 Au) and outlet (~ 40 μg/cm^2 Al) windows. The complete absorption E detector is used as a stop detector- company ORTEC high-purity silicon; thickness of 2 mm. The more detailed description of the experimental setup is given in [10]. Targets were thin metal foils made of 90% enriched boron-11 isotope with thickness of ~ 320 μg/cm^2. The detailed description of targets preparation and measuring the thicknesses of the targets is given in [10]. Typical energy spectrum of 29 MeV alpha particles scattered by ^{11}B is given in Fig. 1.

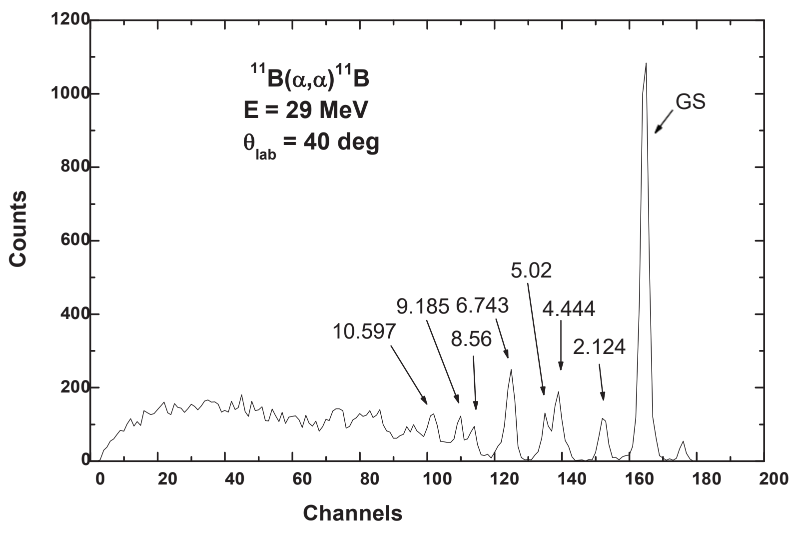

FIGURE 1. Energy spectrum of alpha particles scattered from ^{11}B at 40 degrees in laboratory frame, E(α)=29 MeV

ANALYSIS AND DISCUSSION

In the present calculations for elastic scattering, we have used both a phenomenological optical and double-folding real potentials with a volume type imaginary potential [8]. The theoretical calculations of the angular distributions for the different excited states were performed using the coupled channel (CC) method implemented in code FRESCO [11] using different potential sets [8]. The most appropriate potential set which fairly could describe the elastic scattering was used in the CC calculations for the excited states. In CC calculations we should provide the code with some information about the concerned state (such as spin, parity, excitation energy) and also deformation parameter (β).

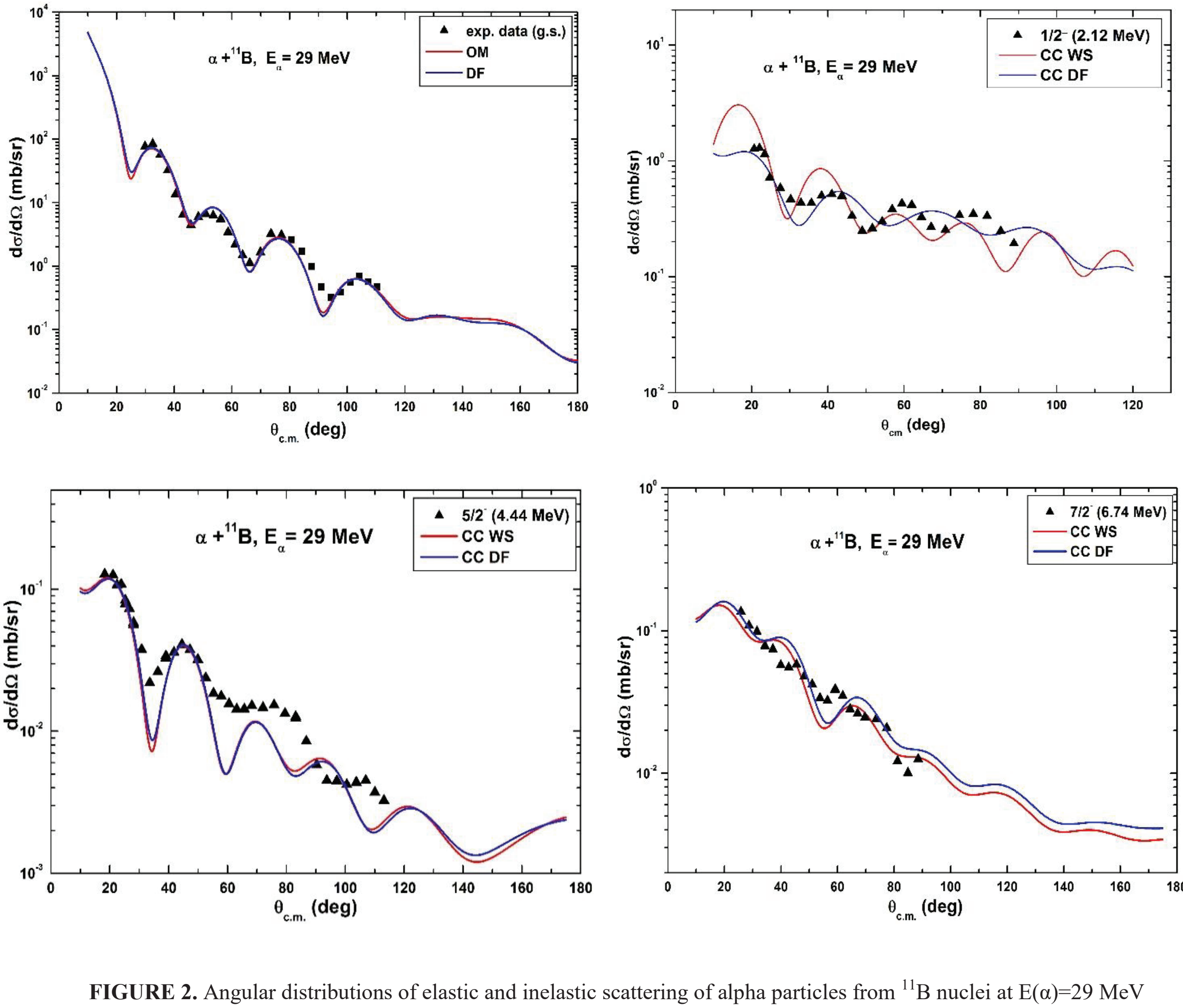

FIGURE 2. Angular distributions of elastic and inelastic scattering of alpha particles from ^{11}B nuclei at E(α)=29 MeV with excitement of 2.12 MeV ($1/2^-$), 4.44 MeV ($5/2^-$) and 6.74 MeV ($7/2^-$) states in comparison with calculated differential cross sections

The angular distributions for excited states 2.12 MeV ($1/2^-$), 4.44 MeV ($5/2^-$) and 6.74 MeV ($7/2^-$) of ^{11}B nuclei were analyzed within the CC method. In the calculations we used the Wood-Saxon potential with a set of parameters CC (WS) and double folding potential CC (DF) from table 1 [8].

The comparison between the experimental data and theoretical predictions for the ground and excited states 2.12 MeV ($1/2^-$), 4.44 MeV ($5/2^-$) and 6.74 MeV ($7/2^-$) at energy E(α) = 29 MeV is shown in Fig. 2.

TABLE I. The optical and double folding potential parameters obtained for elastic and inelastic scattering of α particles from ^{11}B at 29 MeV

Potential set	V_0, MeV	r_v, fm	a_v, fm	N_r	W_0, MeV	r_w, fm	a_w, fm	r_C, fm
OM	79.55	1.20	0.74		37.13	1.80	0.36	1.3
DF				1.23	37.13	1.80	0.36	1.3

Estimation of ^{11}B excited states radii

As noted above, the excited state of $3/2^-$ (8.56 MeV) (Fig. 3) in ^{11}B probably has a cluster structure and is analogous to the Hoyle state (7.65 MeV) in ^{12}C. In our work [12], the rms radius of a given state were calculated at different energies, which showed that this state actually have an increased radius. It was decided to make calculations of the rms radii of the remaining identified excited states up to ~ 7 MeV in order to show the uniqueness of $3/2^-$ (8.56 MeV) state. The rms radii of $3/2^-$ (0 MeV), $1/2^-$ (2.12 MeV), $5/2^-$ (4.44 MeV) and $7/2^-$ (6.74 MeV) states were estimated within MDM [9]. This method allows determining rms radius R^* of the excited state via the difference of diffraction radii of the exited and the ground states using the expression.

$$R^* = R_0 + [R^*_{dif} - R_{dif}(0)] \tag{1}$$

Here R_0 is the rms of the ground state of the studied nucleus, R^*_{dif} and $R_{dif}(0)$ are the diffraction radii determined from the positions of the minima and maxima of the experimental angular distributions of elastic and inelastic scattering correspondingly. The more detailed description of MDM is given in [9]. The rms radii of $3/2^-$ (0 MeV), $1/2^-$ (2.12 MeV), $5/2^-$ (4.44 MeV), $7/2^-$ (6.74 MeV) states in comparison with $3/2^-$ (8.56 MeV) [12] are given in table 2 at E(α)=29 MeV. The value of $3/2^-$ (8.56 MeV) is ~ 1.25 times greater than ones for the ground state. Whereas the radii for $1/2^-$ (2.12 MeV), $5/2^-$ (4.44 MeV), $7/2^-$ (6.74 MeV) are close to the ones for ground state and which once again underlines the uniqueness of $3/2^-$ (8.56 MeV) state.

TABLE II. RMS radii of ground and excited states of ^{11}B, obtained within MDM

E_{lab}, MeV	R_{rms} (g.s.), fm	Excited states			
		R_{rms} (2.12 MeV), fm	R_{rms} (4.44 MeV), fm	R_{rms} (6.74 MeV), fm	R_{rms} (8.56 MeV), fm [12]
29	2.29	2.33 ± 0.10	2.25 ± 0.12	2.25 ± 0.15	2.88 ± 0.16

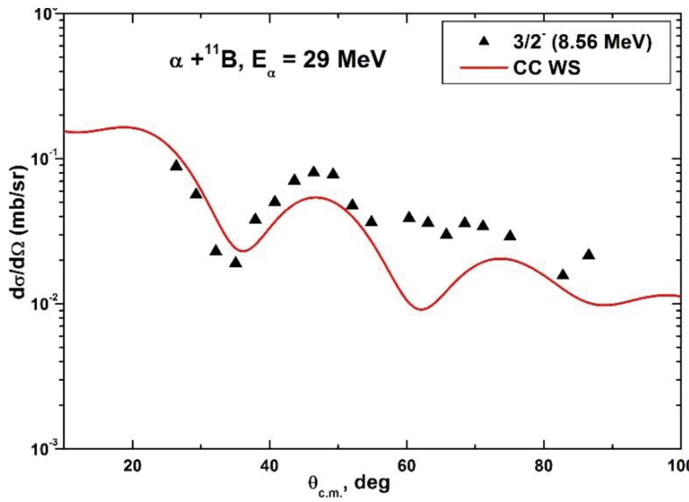

FIGURE 3. Angular distributions of inelastic scattering of alpha particles from ^{11}B nuclei at E(α)=29 MeV with excitement of 8.56 MeV (3/2$^-$) state in comparison with calculated differential cross sections(red line) [12]

CONCLUSION

We obtained new experimental data for the elastic and inelastic with excitation states 2.12 MeV (1/2$^-$), 4.44 MeV (5/2$^-$) and 6.74 MeV (7/2$^-$) scattering of α particles from ^{11}B target at E(α)=29 MeV. The data for the excited states were analyzed within the framework of CC method with two different potentials: usual optical-model potential (phenomenological) and double- folding potential (semi-microscopic).

The analysis carried out within the framework of the MDM showed that the rms radii of these excited states are similar and 20-25% less than the rms radius of the exotic 8.56 MeV (3/2$^-$) state.

The obtained results demonstrate a coexistence of different structures in ^{11}B, thereby showing the uniqueness of the 8.56 MeV (3/2$^-$) state.

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