EPJ Web of Conferences 66, 03007 (2014)
DOI: 10.1051/epjconf/20146603007

Cluster states in ^{11}B

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Abstract. The differential cross-sections of the elastic and inelastic $^{11}B + \alpha$ scattering was measured at E(α) = 65 MeV. The analysis of the data by Modified diffraction model (MDM) showed that the RMS radii of the ^{11}B state 3/2$^-$, E* = 8.56 MeV is ~ 0.6 fm larger than that of the ground state. The 12.56 MeV state was not observed contrary to the predictions of the α-condensate model. The 13.1 MeV state was excited with the angular momentum transfer L = 4 confirming its belonging to the rotational band with the 8.56 MeV state as a head.

1 Introduction

Progress in the theory of cluster physics, in particular, the hypothesis about possible existence of the alpha-particle condensate in nuclei initiated work to find nuclear states with extremely large size. It was predicted that two levels in ^{11}B: ½$^-$, E * = 8.56 MeV and ½$^+$ (possibly at 12.56 MeV) have the root mean square radii R_{rms} = 3.1 fm [1] and ~ 6 fm [2] correspondingly, while the ground state has R_{rms} = 2.29 fm.

For checking these predictions differential cross sections of the inelastic scattering $\alpha + {}^{11}B$ at E(α) = 65 MeV were measured and analyzed together with the data obtained at different energies. The analysis was done by the Modified Diffraction Model (MDM) [3]. This method allows determining the radii R^*rms of the excited states via the difference of the diffraction radii of the excited and the ground states using the expression:

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

Here R_0 is the RMS of the ground state of the nucleus under discussion, 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 the inelastic and elastic scattering correspondingly. Such approach allowed finding the

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consistent values of the RMS radius of the Hoyle state from ^{2}H, ^{3}He, ^{4}He, ^{6}Li, ^{12}C inelastic scattering measured on the ^{12}C target in a wide energy range [4]. The goal of the experiment was to determine the radii values of the exciting states in ^{11}B using MDM.

2 Experimental data

We measured the differential cross-sections of the inelastic $\alpha + {}^{11}B$ scattering with excitation the states of ^{11}B up to E^{*} ~ 14 MeV. The experiment was done at the JYFL cyclotron K130, Jyvaskyla University, Finland using LSC (Large Scattering Chamber) with ΔE-E telescopes of semiconductor counters. The target was an ^{11}B self-supported film of 0.275 mb/cm^2 thickness. The only significant impurity was ^{12}C. The beam monochromatization system was used allowing providing the total energy resolution of the experiment to be 150 keV.

A sample spectrum is shown on Fig. 1.

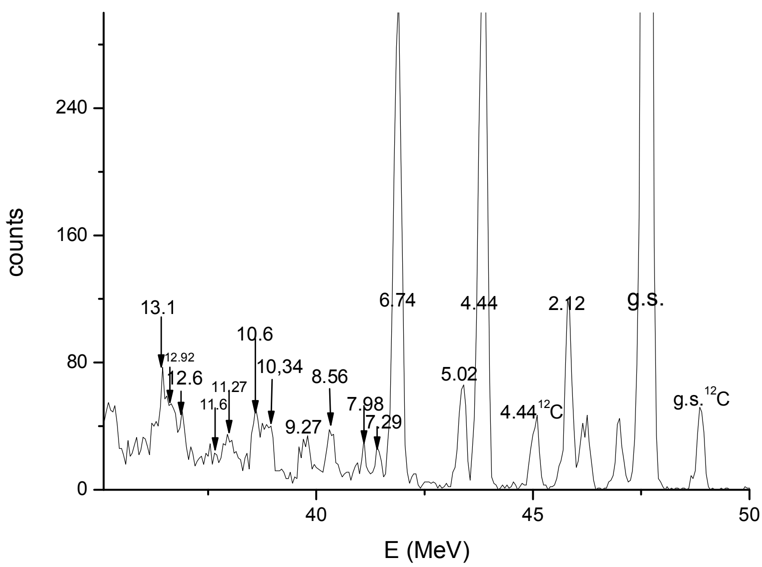

Figure 1. A sample α-particles spectrum at E (α) =65 MeV, Θ=53.5 deg.

3 Results and discussions

3.1 8.56 MeV state

The value of the 8.56MeV state radius was determined to be R_{rms} = 2.87 ± 0.12 fm, which is 0.6 fm larger than the radius of the ground state being in agreement with the previous data (R_{rms} = 2.99 ± 0.18 fm from Ref. [5]).

The obtained radius is practically equal to the radius of the second excited state of ^{12}C, the Hoyle state. The radius of the Hoyle state was determined to be R_{rms} = 2.89 ± 0.04fm [3].

So the obtained result together with the similarity of the shapes of the angular distributions (Fig. 2) and the similarity of the energy dependence of diffraction radii (Fig. 3) clearly indicates to the similarity of the structures of the 8.56 MeV state of ^{11}B and the Hoyle state of ^{12}C. The 8.56 MeV state can be considered as an analogue of the Hoyle state in neighboring nuclei.

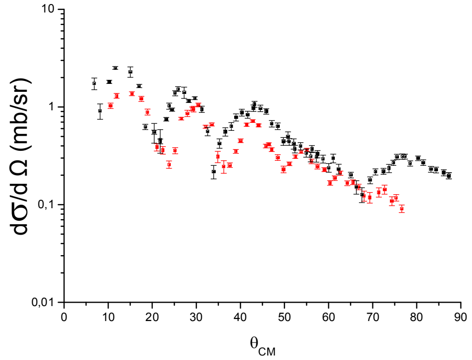

Figure 2. Differential cross-sections of inelastic scattering $\alpha + {}^{11}B$ at E_α=65 MeV leading to 8.56 MeV state (red points) and inelastic scattering $\alpha + {}^{12}C$ at E_α=65 MeV leading to 7.65 MeV state (black points)

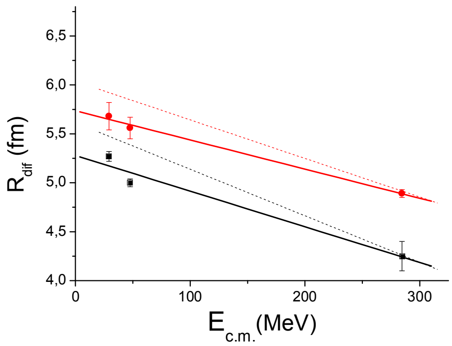

Figure 3. Energy dependence of diffraction radii: black dashed line – diffraction radii for elastic scattering $\alpha + {}^{12}C$, red dashed line – for 7.65 Hoyle state, black points – for elastic $\alpha + {}^{11}B$, black solid line – linear fit for black points, red points – for 8.56 MeV state, red solid line – linear fit for red points

3.2 Rotational band based on 8.56 MeV state

We got preliminary results for the differential cross-section of the inelastic scattering leading to 10.34 MeV ($5/2^-$) and 13.1 MeV ($9/2^-$) states. These states are predicted [6,7] as the second and the fourth members of the rotational band based on the 8.56 MeV state. The behavior of the angular distribution of the inelastic scattering with the excitation of the 13.1 MeV state is the same as for the inelastic scattering of $\alpha + {}^{12}C$ with the excitation of the 14.08 MeV (Fig. 4). The last is well known to be excited by transition L=4. The MDM was used for estimating the radius of the 13.1 MeV state. The best fit was obtained with the diffraction radius R_{dif}=4.5 fm, the value which coincides with that of the L = 4 transition in the ${}^{12}C$ (α, α') reaction to a new state of ${}^{12}C$ at E* = 13.75 MeV [8] belonging to the rotational band based on the Hoyle state. In some articles [6] there are assumptions that the 13.1 MeV state is the member of the hypothetical rotational band based on the ground state. Within these assumptions the previous member of this band is the 6.74 MeV state with abnormally large inertia momentum. We have got the angular distribution with the excitation of this state and didn't observe any RMS radius enlargement, what is naturally can be expected in accordance with sharp increase of inertia momentum. It is quite possible that abovementioned rotational band doesn't exist and low-lying states of ${}^{11}B$ have normal shell-model structure. So the 13.1 MeV is more probable to be the member of the band based on the 8.56 MeV state.

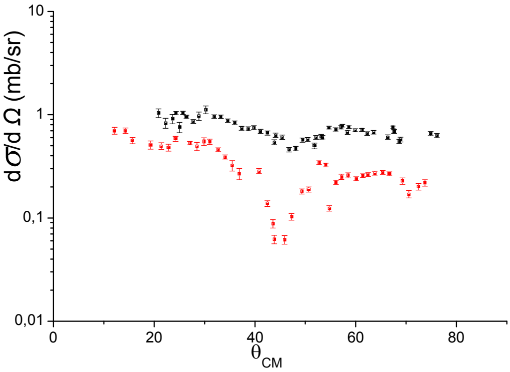

Figure 4. Differential cross-sections of inelastic scattering α + ^{11}B at E_α = 65 MeV leading to 13.1 MeV state (red points) and inelastic scattering α + ^{12}C at E_α = 65 MeV leading to 14.08 MeV state (black points)

3.3 12.56 MeV state

For the 12.56 MeV (½$^+$, T=3/2) state [9] of ^{11}B there exists contradictory information concerning its isospin. The model [2] suggest that J^π=½$^+$, T = ½.

In our experiment we observed a group of states, among them is the state with excitation energy 12.6 MeV. Also such state was detected in the resonance reaction ^{7}Li + α [6]. A T = 3/2 state is unexpected to be observed in the inelastic alpha particle scattering, so isospin of this state is T = ½.

Preliminary analysis of angular distribution indicates to angular transferred momentum L=1, so spin of this state is 3/2$^+$, in agreement with [6]. Thus, we can conclude that the predictions [2] were not confirmed.

Theoretical calculations are in a progress.

The work was supported by the Grant of RFBR, No 12-02-000927-a.

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