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Cluster rotational bands in ^{11}B

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Abstract

Differential cross-sections of ^{11}B+α inelastic scattering at $E(\alpha) =$ 65 MeV leading to most of the known ^{11}B states at excitation energies up to 14 MeV were measured [1]. The data analysis was done using Modified diffraction model (MDM) [2] allowing determining radii of excited states. Radii of the states with excitation energies less than $\sim$ 7 MeV coincide with the radius of the ground state with an accuracy not less than 0.1 - 0.15 fm. This result is consistent with traditional view on shell structure of low-lying states in ^{11}B. Most of the observed high-energy excited states are distributed among four rotational bands. Moments of inertia of band states are close to the moment of inertia of the Hoyle state of ^{12}C. The calculated radii, related to these bands, are 0.7 - 1.0 fm larger than the radius of the ground state, and are close to the Hoyle state radius. These results are in agreement with existing predictions about various cluster structure of ^{11}B at high excitation energies.

1 Introduction

During long time ^{11}B nucleus was considered as a good example of shell effects in light nuclei. Up to excitation energies $\sim$ 7 MeV ^{11}B states were described by different variants of shell models. Recently, however, a number of theoretical and experimental works appeared [3–5] with predictions about cluster configurations of various types co-existed in ^{11}B.

Particular attention was drawn to the idea that there may be states in ^{11}B, which are analogs of the famous 0_2^+ state in ^{12}C nucleus (the so-called Hoyle state). The Hoyle state consists of three weakly interacting alpha - clusters and its properties were crucial for verification of the alpha - particle condensation theory [6]. One of the main suggestions of this theory is abnormally large radius of the Hoyle state. Accordingly, Hoyle state analogs in ^{11}B must also have increased size.

It was assumed [3] that the Hoyle state analog in ^{11}B is the state $3/2^-$ with excitation energy 8.56 MeV, which is not described by any variant of the shell model. The radius of 8.56 MeV state was considered to be abnormally large, and it was predicted that this state is a base for rotational band.

There are a lot of experimental studies of ^{11}B (see, e.g., [7] and references therein), but they did not affect the excitation energy region of interest for the problem. Due to the fact that many questions about ^{11}B states remained open, we have undertaken a new study of inelastic ^{11}B + α scattering at $E(\alpha)$ = 65 MeV [1]. Experimental results were analyzed using Modified diffraction model (MDM). In this article we discuss results for high-energy excited states and possible cluster rotational bands formed from them.

2 Radii and moments of inertia of high-lying rotational bands in ^{11}B

The following rotational bands were predicted [3,5] in high excitation energy region in ^{11}B. Most of these states were observed in our experiment:
$K = 3/2^-$: 8.56 ($3/2^-$) - 10.34 ($5/2^-$) - 11.60 - 13.14 ($9/2^-$) MeV,
$K = 1/2^+$: 6.79 ($1/2^+$) - 9.88 ($3/2^+$) 11.60 ($5/2^+$) 13.16 ($7/2^+$) MeV,
$K = 3/2^+$: 7.98 ($3/2^+$) - 9.27 ($5/2^+$) - 10.60 ($7/2^+$) - 12.63 ($9/2^+$) MeV,
$K = 5/2^+$: 7.29 ($5/2^+$) - 9.19 ($7/2^+$) - 11.27 ($9/2^+$) MeV.

These rotational bands are shown in Fig. 1 together with the band in ^{12}C, based on the Hoyle state. Data on angular momentum transfer with excitation states belonging to the specified bands, received from our experiment, are in agreement with known spin-parities of ^{11}B states. However, for 6.79, 9.88, 10.34, 13.14 13.16 MeV states it could not determined unambiguously due to insufficient energy resolution. Several special features in $J(J+1)$ dependence of excitation energies can be seen in Fig. 1. Firstly, moments of inertia of the band states are very high and comparable. The largest of them ($2I/\hbar^2 \sim 4.0$, by the energy difference between the excitation

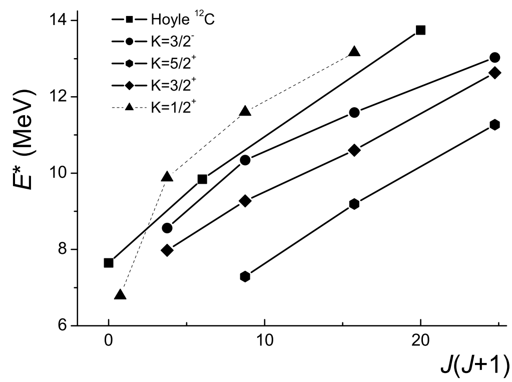

Figure 1: Predicted [3,5] rotational bands in ^{11}B at excitation energies $E^* > 7$ MeV. For comparison, rotational band [8], based on the Hoyle state (0_2^+, 7.65 MeV) of ^{12}C, is shown.

energies 11.60 and 10.34 MeV) are observed for higher members of the rotational band $K = 3/2^-$, for which cluster structure $2\alpha + t$ is predicted. It is interesting that it is much larger than the moment of inertia of its analog - the Hoyle state, for which $2I/\hbar^2 = 2.7$. Secondly, there is a clear correlation between the moments of inertia and the values of radii obtained from scattering data using MDM. Low-lying states of ^{11}B have "normal" radii and "reduced" moments of inertia about $2I/\hbar^2 \sim 1.1$. These values are close to values for the first excited state of ^{12}C, 4.44 MeV. "Big" moments of inertia correspond to increased radii. Summary of the radii of the states measured using MDM is given in the Fig. 2.

As seen from Fig. 2, increased radii were found, at least, for one of the members of each band, and in most cases they are about 0.7 - 1.0 fm larger than the radius of the ground state of ^{11}B. This leads to the conclusion that all states belonging to the bands under consideration, have abnormal size. Theoretical works [3–5] suggest a significant deformation of the rotational states of ^{11}B with $E^* > 7$ MeV and it allows the increase of their radii. The radii and moments of inertia of these states are close to the corresponding values of the Hoyle state in ^{12}C nucleus and the rotational band based on it. These facts indicate probable cluster nature of the ^{11}B states discussed. In particular, the 8.56 MeV state can be considered as an analog of the Hoyle state. But some open questions remain regarding the rotational band that is based on the 6.79 MeV state, including the very existence of band [1].

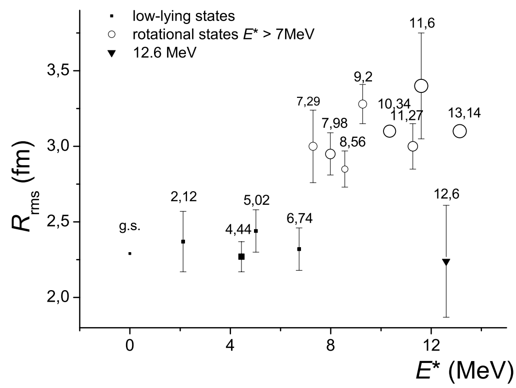

Figure 2: Dependence of R_{rms} (root-mean-square radii, determined by MDM) on the excitation energy for states of ^{11}B. The sizes of the plotted points are proportional to the moments of inertia of the states.

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References

[1] A.N. Danilov, A.S. Demyanova et al., Physics of Atomic Nuclei 78, No. 6, 777 (2015)

[2] A.N. Danilov et al., Phys.Rev. C 80, 054603 (2009)

[3] Y. Kanada-Enyo, Phys. Rev. C 75, 024302 (2007)

[4] T. Yamada and Y. Funaki, Phys. Rev. C 82, 064315 (2010)

[5] H. Yamaguchi et al., Phys. Rev. C83, 034306 (2011)

[6] 6. A. Tohsaki, H. Horiuchi, P. Schuck, and G. Ropke, Phys. Rev. Lett. 87, 192501 (2001)

[7] N. Burtebaev et al., Physics of Atomic Nuclei68, 1303 (2005)

[8] A.A. Ogloblin et al., EPJ Web of Conferences, 66, 02074, (2014)