Band structure in ^{12}Be

Bohlen, H.G.; Von Oertzen, W.; Wheldon, Tzanka; Schulz, Ch.; Kalpakchieva, R.; Massey, T.N.; Milin, M.

DOI:

[10.1142/S0218301308011100](https://doi.org/10.1142/S0218301308011100)

Document Version

Publisher's PDF, also known as Version of record

Citation for published version (Harvard):

Bohlen, HG, Von Oertzen, W, Wheldon, T, Schulz, C, Kalpakchieva, R, Massey, TN & Milin, M 2008, 'Band structure in ^{12}Be : Experiment results', *International Journal of Modern Physics E*, vol. 17, no. 10, pp. 2067-2070. <https://doi.org/10.1142/S0218301308011100>

[Link to publication on Research at Birmingham portal](#)

General rights

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

Take down policy

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact UBIRA@lists.bham.ac.uk providing details and we will remove access to the work immediately and investigate.

BAND STRUCTURES IN ^{12}Be : EXPERIMENTAL RESULTS

H. G. BOHLEN, W. VON OERTZEN*, TZ. KOKALOVA[†] and CH. SCHULZ

*Helmholtz-Zentrum Berlin,
Glienicker Str. 100, D-14109 Berlin, Germany
bohlen@helmholtz-berlin.de*

R. KALPAKCHIEVA

*Flerov Laboratory of Nuclear Reactions, JINR,
141980 Dubna, Moscow region, Russia*

T. N. MASSEY

*Department of Physics and Astronomy, Ohio University,
Athens, OH 45701-2979, USA*

M. MILIN

*Ruđer Bošković Institute,
Bijenicka 54, HR-10002 Zagreb, Croatia*

The structure of the neutron-rich isotope ^{12}Be has been studied using different transfer reactions, which populate distinct structures in ^{12}Be . This concerns two-neutron and three-neutron stripping reactions and two-proton pick-up reactions at incident energies of 15–20 MeV/u. Band structures of positive and negative parity are discussed.

1. Introduction

In neutron-rich Beryllium isotopes pronounced cluster structures can be found. These structures are strongly deformed and therefore rotational bands are built upon. In ^{12}Be for example, a molecular band has been found by M. Freer *et al.*¹ using angular correlation measurements for the two ^6He fragments or the $^8\text{He} + ^4\text{He}$ fragments (Figs. 1(b), (c)) after inelastic excitation of the corresponding 4^+ , 6^+ , 8^+ band members (however, in a recent measurement at higher incident energy² some of the states were not confirmed). The 0^+ and 2^+ members of this band have been identified at 10.9 MeV and 11.3 MeV,³ respectively, from the characteristic shapes of angular distributions for $\ell = 0$ and $\ell = 2$ angular-momentum transfers in inelastic α -scattering on ^{12}Be , in coincidence with the decay particles $^6\text{He} + ^6\text{He}$.

*also Freie Universität, Berlin, Germany.

[†]now at School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, UK.

	^{12}Be	S_x
(a)	$^{10}\text{Be} \times 2n$	3.673 MeV
(b)	$^8\text{He} \times ^4\text{He}$	8.946 MeV
(c)	$^6\text{He} \times ^6\text{He}$	10.11 MeV
(d)	$\alpha \begin{smallmatrix} n & n \\ n & n \end{smallmatrix} \alpha$	12.06 MeV

Fig. 1. Cluster configurations for ^{12}Be (left) and corresponding particle thresholds S_x (right).

In the particle-stable region of excitation energies, below the 1n-threshold of ^{12}Be at 3.168 MeV, four states were known: the 0_1^+ ground state, the 2_1^+ state at 2.10 MeV,^{4,5} the 0_2^+ state at 2.24 MeV,⁶ and the 1_1^- state at 2.68 MeV.⁷ From here up to the α -particle threshold at 8.946 MeV only three states were known: the 2_2^+ state^{4,5} at 4.56 MeV, the state at 5.70 MeV with $(3^-, 4^+)$ assignments,^{4,5} and an unassigned state at 8.6 MeV⁸ observed in inelastic proton scattering in inverse kinematics.

2. Results from the Actual Transfer Reactions

We have used three different types of transfer reactions, each of which is populating primarily a distinct structure in ^{12}Be , as will be shown in the following. These reactions are:

- (i) The two-proton pickup reaction on ^{14}C :
 $^{14}\text{C}(^{12}\text{C}, ^{14}\text{O})^{12}\text{Be}$, $E_{\text{Lab}} = 231$ MeV, $Q_0 = -30.06$ MeV, $E_x = 0\text{--}20$ MeV
- (ii) The two-neutron stripping reaction on ^{10}Be :
 $^{10}\text{Be}(^{14}\text{N}, ^{12}\text{N})^{12}\text{Be}$, $E_{\text{Lab}} = 216$ MeV, $Q_0 = -26.94$ MeV, $E_x = 0\text{--}20$ MeV
- (iii) The three-neutron stripping reactions on ^9Be :
 - (a) $^9\text{Be}(^{12}\text{C}, ^9\text{C})^{12}\text{Be}$, $E_{\text{Lab}} = 231$ MeV, $Q_0 = -42.64$ MeV, $E_x = 0\text{--}18$ MeV
 - (b) $^9\text{Be}(^{15}\text{N}, ^{12}\text{N})^{12}\text{Be}$, $E_{\text{Lab}} = 240$ MeV, $Q_0 = -30.97$ MeV, $E_x = 5\text{--}26$ MeV

The measurements have been performed at the cyclotron and Q3D magnetic spectrometer of the Helmholtz-Zentrum Berlin (former name until May 2008: Hahn-Meitner-Institut Berlin).

2.1. The two-proton pickup reaction on ^{14}C

The spectrum of the $^{14}\text{C}(^{12}\text{C}, ^{14}\text{O})^{12}\text{Be}$ reaction (not shown here) is rather simple. Only five peaks are observed in the full range of measured excitation energies (for comparison: many more states are populated in the $^{12}\text{C}(^{12}\text{C}, ^{14}\text{O})^{10}\text{Be}$ reaction⁹). Since the actual reaction produces proton-holes in the tightly bound ^{14}C target

nucleus, the largest cross sections occur for the transitions to the ground state and the 2_1^+ state, but also the 2_2^+ state at 4.56 MeV is well populated. The latter is considered to be a member of the 0_2^+ -band, which is located at 2.24 MeV. The corresponding band head could not be resolved from the strong 2_1^+ state at 2.10 MeV, but it has a sizable overlap with the high-energy tail of the 2.10 MeV peak and may be hidden there. Two broad resonances are observed at higher excitation energies, at 9.6 MeV and 18.95 MeV. As a preliminary result, these are considered to form a rotational band together with the 0_2^+ and 2_2^+ states.

2.2. The two-neutron stripping reaction on ^{10}Be

Figure 2 shows the full spectrum of the $^{10}\text{Be}(^{14}\text{N}, ^{12}\text{N})^{12}\text{Be}$ reaction. Since the target material was Beryllium-oxide (BeO), large contributions from ^{16}O are observed, but also some contributions from ^{12}C (the strongest ^{14}C -line at 10.74 MeV is indicated in Fig. 2). Spectra on ^{12}C and ^{16}O (V_2O_5 -material) have been measured separately and their normalizations were fitted simultaneously with the peaks of ^{12}Be . As a result from this analysis it turned out that this reaction also populates only a few states of ^{12}Be , namely the states at 0.00 MeV, 2.10 MeV, 4.56 MeV, 5.70 MeV, 6.25(5) MeV (the latter state was localized only recently in a reanalysis of the spectrum) and 11.2 MeV. In the excitation energy range from 7–20 MeV only one single peak is observed! Obviously the structure of excited states in this range does not fit to a $^{10}\text{Be}_{g.s.}$ core. We will see in the next section, that a $^9\text{Be}_{g.s.}$ core opens the window for the population of many states in this excitation energy region.

Fig. 2. Spectrum of the two-neutron transfer reaction ($^{14}\text{N}, ^{12}\text{N}$) on a ^{10}BeO target at 216 MeV. The sum of background contributions resulting from the ^{16}O and ^{12}C content of the target is indicated by the hatched area with wide spacing, the part from ^{16}O (yellow) is dominant.

2.3. The three-neutron stripping reactions on ${}^9\text{Be}$

The ${}^9\text{Be}({}^{12}\text{C}, {}^9\text{C}){}^{12}\text{Be}$ reaction has a very large negative Q-value, therefore the cross sections are very small. But the resolution is rather good, and narrow states can be well identified even on the background resulting from the ${}^{16}\text{O}$ in the target (see Fig. 3). The new state just above the 5.70 MeV peak is again observed, here at 6.30(5) MeV. In this reaction nine states can be localized at 7–17 MeV excitation energy in contrast to the two-neutron stripping reaction on ${}^{10}\text{Be}$. Such a large number of states is also observed in the ${}^9\text{Be}({}^{15}\text{N}, {}^{12}\text{N}){}^{12}\text{Be}$ reaction (not shown here). The states marked in red in Fig. 3 (upward hatched area) are tentatively assigned as members of a $K=1^-$ band. Details of the analysis will be given in an extended publication.

Fig. 3. Spectrum of the ${}^9\text{Be}({}^{12}\text{C}, {}^9\text{C}){}^{12}\text{Be}$ three-neutron transfer reaction at 231 MeV. The background from the ${}^{16}\text{O}$ target contamination is indicated by the yellow hatched area.

References

1. M. Freer et al., *Phys. Rev. Lett.* **82** (1999) 1383.
2. R. J. Charity et al., *Phys. Rev. C* **76** (2007) 064313.
3. A. Saito et al., *Nucl. Phys. A* **738** (2004) 337.
4. D. E. Alburger et al., *Phys. Rev. C* **18** (1978) 2727.
5. H. T. Fortune, G. B. Liu and D. E. Alburger, *Phys. Rev. C* **50** (1994) 1355.
6. S. Shimoura and A. Saito et al., *Phys. Lett. B* **560** (2003) 31.
7. H. Iwasaki and T. Motobayashi, et al., *Phys. Lett. B* **491** (2000) 8.
8. A. A. Korshennikov et al., *Phys. Lett. B* **343** (1995) 53.
9. H. G. Bohlen et al., *Phys. Rev. C* **75** (2007) 054604.