1-1-2013

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Recommended Citation

Rogachev, G., Baby, L., Belarge, J., Blackmon, J., Goldberg, V., Johnson, E., Koshchiy, E., Kuchera, A., Lai, J., Linhardt, L., MacOn, K., Matos, M., Santiago-Gonzalez, D., & Wiedenhöver, I. (2013). Clustering in A=10 nuclei. *Journal of Physics: Conference Series, 436* (1) https://doi.org/10.1088/1742-6596/436/1/012041

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To cite this article: G V Rogachev *et al* 2013 *J. Phys.: Conf. Ser.* **436** 012041

Journal of Physics: Conference Series **436** (2013) 012041 doi:10.1088/1742-6596/436/1/012041

Clustering in A=10 nuclei

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Abstract. We discuss the identification and properties of the states that belong to the highly clustered rotational band in A=10 nuclei, ^{10}Be, ^{10}B(T=1) and ^{10}C. The band is of interest because it may correspond to an exotic α:nn:α configuration.

1. Introduction

It has been suggested in several theoretical papers (see *e.g.* [1, 2, 3]) that highly clustered, double α-core structure, α:nn:α, may exist in A=10 T=1 nuclear systems. This structure would form a positive-parity rotational band (Fig. 1) based on the 0^+_2 state (0^+ at 6.17 MeV, 2^+ at 7.54 MeV and 4^+ at 10.15 MeV). Multiple experimental searches for the members of this band in ^{10}Be and ^{10}B have been performed [4, 5, 6, 7, 8]. We present new experimental data on the states in ^{10}Be populated in the ^{6}He+α interaction and discuss the spectrum of T=1 states in ^{10}B and ^{10}C in relation to the 0^+_2 rotational band.

2. Cluster States in ^{10}Be

Cluster states in ^{10}Be were searched for in the excitation function of ^{6}He+α elastic scattering which was measured in the excitation energy range between 9 and 18.5 MeV. Measurements were performed at the John D. Fox Superconducting Linear Accelerator Laboratory at Florida State University. The ^{6}He beam was produced by the in-flight rare isotope beam facility RESOLUT with intensity of about 10^5 pps. The new active target detector - Array for Nuclear Astrophysics and Structure with Exotic Nuclei (ANASEN) - was used to perform the measurements. ANASEN is a gas filled detector, which has an array of position sensitive silicon detectors that surrounds the beam axis and a cylindrical array of position sensitive proportional counters. The recoils that emerge from the place of interaction go through the proportional counter first. The location and energy loss in the active gas volume is measured. If the second hit is recorded by the silicon detector then the track of the recoil can be reconstructed using position information provided by the proportional counter and the silicon array. Particle ID is determined using energy loss in the active gas volume and the total energy measured by the silicon array. The ^{6}He+α elastic scattering events can be identified using the energy-angle kinematic dependence reconstructed from the tracks of the recoils.

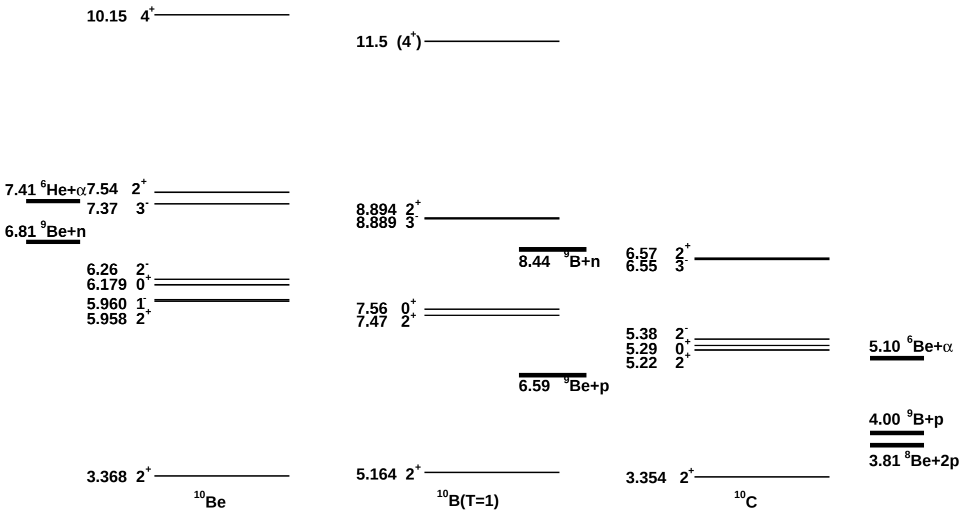

Figure 1. Level diagram for T=1 isobaric multiplet in A=10

We limit our discussion to the lower energy part of the ^{6}He+α elastic scattering excitation function. The energy range between 2 and 3.5 MeV in c.m.s. (9.5 and 11 MeV excitation energy) is shown in Fig. 2. The obvious feature of this excitation function is the peak at 2.75 MeV (10.16(2) MeV excitation energy). This is the state that was first observed in [4] and [5]. The 3^- spin-parity was assigned to it in [7]. However, this was contradicted by [8] where the ^{6}He+α angular distribution at 2.75 MeV energy in c.m. showed a maximum at 90 degrees, indicating positive parity. The 4^+ spin-parity assignment was made for the state in [8]. The excitation function was not measured in [8] and both the location and the width of the state were adopted from [7]. In this work we clearly observed the strong state at 10.16(2) MeV excitation energy in ^{10}Be with a width of 270(30) keV. The angular distribution for this state is shown in Fig. 2. Comparing this angular distribution to the squared Legendre polynomials give a unique spin-parity assignment for the state in question. We confirm the 4^+ spin-parity assignment for this state first made in [8]. The partial α width for the 10.16 MeV state is 150 keV. It was determined from the measured cross section and the total width of this state. This partial width exceeds the single-particle limit for the purely α-cluster states. Therefore, our data provide unambiguous evidence that the 10.16 MeV state is 4^+ and it has an extreme α-cluster character.

The 10.16 MeV state has been suggested as a possible member of the highly clustered 0_2^+ rotational band in [5]. Our data strongly support this suggestion. The degree of clustering for the other members of this rotational band in ^{10}Be, the 0^+ state at 6.18 MeV and the 2^+ state at 7.54 MeV is uncertain. The branching ratio $\Gamma_\alpha/\Gamma=3.5(12)\times10^{-3}$ for the 2^+ state at 7.54 MeV reported in [9] would indicate a huge partial α width, 30-50 times above the single particle limit. Considering the experimental uncertainty of this measurement and unusually large value for the partial α width, independent confirmation is required.

3. The 0_2^+ band members in ^{10}B and ^{10}C

The spectrum of the T=1 states in ^{10}B has been studied recently in [10] using the ^{9}Be(^{1}H,α)^{6}Li(0^+; T=1) reaction. The partial α-width of the T=1 2^+ state at 8.89 MeV in ^{10}B, the isobaric analog of the 2^+ at 7.54 MeV in ^{10}Be was determined using R-matrix analysis of the ^{9}Be(^{1}H,α)^{6}Li(0^+; T=1) excitation function. Its value, 18±2.0±2.3(sys) keV corresponds

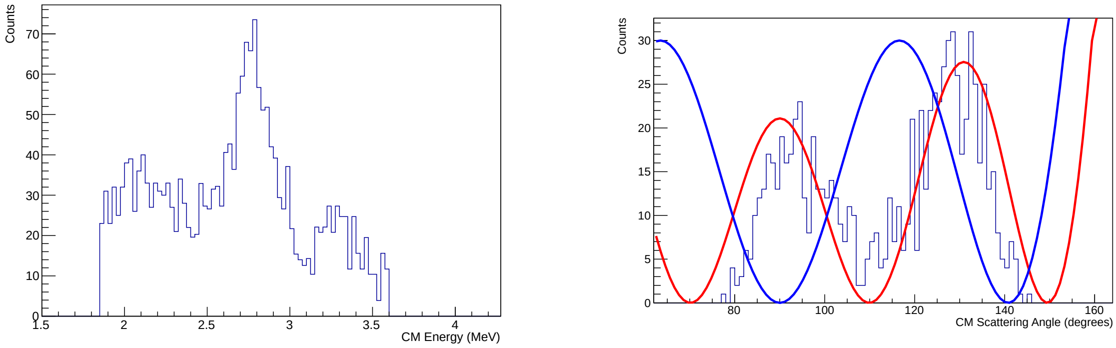

Figure 2. Left figure: Excitation function for the ^{6}He+α elastic scattering integrated over angular range from 90 to 140 degrees. Right figure: Angular distribution at 2.75±0.1 MeV in c.m.s. Red and blue curves corresponds to the square of L=4 and L=3 Legendre polynomials, respectively.

to the α single particle limit and clearly identifies this state as an extremely clustered structure. A similar conclusion can be found in [11]. The T=1 4^+ state in ^{10}B, the isobaric analog for the 10.16 MeV state in ^{10}Be is expected at excitation energy close to 11.5 MeV. No 4^+ state has been observed near that energy in [10]. However, in [12] a state at 11.5 MeV that decays by α emission to the ^{6}Li(0^+;T=1) and has small nucleon width has been observed. It is possible that because of the ^{9}Be+p entrance channel for the reaction used in [10] the 4^+ state was not populated. The reaction ^{11}B(^{3}He,α)^{10}B used in [12] does not have this limitation.

Spin-parity assignment of the states in ^{10}C is uncertain. However, recent analysis of the decay spectroscopy experiments [13] allows to make a suggestion that the state at 5.29 MeV and 6.57 MeV (Fig. 1) have large partial α widths (compared to α single particle limit) and small nucleon width. A particularly interesting feature of these states is their relatively large two proton decay branching ratio. It is argued in [14] that these states are highly clustered 0^+ and 2^+ states that belong to the 0_2^+ band. Confirming these spin-parity assignments and accurately measuring decay branching ratios would allow determination of the partial α width for the 0_2^+ state and, provided that it is large, firmly establish the highly clustered nature of the 0_2^+ band. The moment of inertia for this band is a factor of three larger than for the ground state band. This corresponds to the effective radius that is a factor of 1.8 larger than for the states in the ground state band. This was accurately predicted by the AMD calculations [1].

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