Cluster Structure of states in ^{11}B and ^{11}C

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Abstract

We propose to probe the structure of T=1/2 and T=3/2 isobaric analogue states in ^{11}B and ^{11}C, using breakup techniques in order to determine their overlap with α+t+α, α+p+2n+α, α+^{3}He+α and α+2p+n+α molecular structures. The measurement will involve a study of the ^{7}Li(^{9}Be,^{11}B[^{10}Be,p]), ^{7}Li(^{9}Be,^{11}B[α,α,t]), ^{16}O(^{9}Be,^{11}C[^{10}B,p]) and ^{16}O(^{9}Be,^{11}C[α,α,^{3}He]) reactions with E_{beam}=65 MeV, the breakup products will be detected in an array of charged particle detectors.

Introduction

The concept of groups of atoms being covalently bound into molecules by valence electrons, via the exchange interaction, was established by Heitler and London in 1927 in their study of the H_2 molecule [1]. However, recent studies suggest that such phenomena may also be present on the nuclear scale [2-5]. For example, von Oertzen [4-5] has developed a description of the low-lying states of ^{9}Be and ^{9}B in terms of α+n+α and α+p+α molecular structures respectively. In the case of ^{9}Be the additional neutron provides the binding for the unbound ^{8}Be subsystem, much as the covalent binding of the H_2^+ molecule. Interestingly, the two-centre orbits in which the valence neutron resides, closely resemble those in the atomic molecules, promoting the concept of covalent binding on the nuclear scale, in the form of "molecular analogue" states.

These ideas extend to the multi-valence particle nuclei ^{10}Be, ^{10}C, ^{10}B, ^{11}Be, ^{11}B, ^{11}C, ^{11}N, etc… In fact, our recent experimental measurement of the breakup of ^{12}Be into helium isotopes indicates that this nucleus has states which may be associated with a ^{6}He+^{6}He cluster structure which may be the continuation of this sequence to A=12 isobars (M. Freer, et al., submitted to Phys. Rev. Lett. [6]). In recent years, particular interest has focussed on the unusual structural properties of ^{11}Be. The halo type-structure of this nucleus arises primarily from the rearrangement of the single-particle levels that has been observed for light proton and neutron rich nuclei. This produces the $2s_{1/2}$ intruder level that is believed to account, to a large extent, for the occurrence of the $1/2^+$ ground state spin and parity. It is this intruder level which also gives rise to the halo structure due to the absent centrifugal barrier. The low-lying states in ^{11}Be have T=3/2 isobaric analogues in ^{11}B, $1/2^+$ (12.56 MeV), $1/2^-$ (12.91 MeV), 5/2 (14.33 MeV) and (3/2, 5/2, 7/2) (15.32 MeV). Similarly, there is also a collection of isobaric analogue states in ^{11}C in the region E_x > 12 MeV. A study of the structural properties of the T=3/2 isobaric analogue states in ^{11}B and ^{11}C could provide an important insight into the structure of ^{11}Be. For example, the decay probability of the ^{11}B T=3/2 states to the ^{10}Be ground and first excited states, can provide information on the $2s_{1/2}$ and $1d_{5/2}$ contributions to the ^{11}Be ground state – a long standing question. Further, such measurements could provide evidence for both α+3n+α, α+2n+p+α and α+2p+n+α molecular type structures in these nuclei. The valence neutrons and protons in these states are not in common orbits so for the latter two examples the 2n+p and 2p+n structures cannot be linked with ^3H and ^3He clusters respectively. Such $\alpha+^3H+\alpha$ and $\alpha+^3He+\alpha$ structures will be linked to T=1/2 states in these nuclei and are, as yet, unidentified.

Proposed Measurements

We propose to use the isospin allowed reactions $^7Li(^9Be,^{11}B)^5He$, Q=+6.19 MeV, and $^{16}O(^9Be,^{11}C)^{14}C$, Q=-7.06 MeV, to access the T=1/2 and T=3/2 states in ^{11}B and ^{11}C. These reactions provide an important link to the cluster states for two reasons. Firstly, the ^9Be nucleus is believed to possess a well-developed α+n+α cluster structure in the ground state, so the sequential transfer of n+p or p+p from the target might be expected to strongly excite the molecular states in ^{11}B and ^{11}C. Secondly, the ground and low-lying T=3/2 states in ^{11}Be are strongly excited in the 2n transfer reactions $^9Be(t,p)$ [7] and $^9Be(^{13}C,^{11}C)$ [8]. The reaction thus would provide a strong link to the α+X+α molecular type structures.

The population of the states in ^{11}B and ^{11}C is to be observed via their decay into the proposed cluster components. These decay products will be detected in an array of charged particle detectors, and using the technique of invariant mass spectroscopy the excitation energy prior to decay will be reconstructed. A number of decay paths involving the emission of charged particles are open, for example, for ^{11}B: ^8Be+t (Q= - 11.22 MeV), $^7Li+\alpha$ (Q= - 8.66 MeV), ^{10}Be+p (Q=-11.23 MeV) and ^9Be+d (Q=-15.82 MeV). [^{11}C: $^8Be+^3He$ (Q= - 9.22 MeV), $^7Be+\alpha$ (Q= -7.54 MeV), ^{10}B+p (Q=-8.69 MeV) and ^9B+d (Q=-14.90 MeV).] An examination of the decay strengths to all of these final states should provide an important indication of the structure of the excited states. For example, the T=3/2 states are observed in the $^{10}Be(p,\gamma)$ reaction [9], this might indicate that the molecular content of these T=3/2 states is small (since the ^{10}Be ground state has small deformation) . The T=3/2 states in ^{11}C, on the other hand, are forbidden to decay to the ^{10}B ground state, decaying instead to the T=1, 2.15 MeV excited state [9], which again has no association with a molecular configuration. However, it is possible to observe the decay to the collection of (T=1) states at ~5 to 7 MeV in $^{10}B(^{10}Be)$, which have been linked with the α+d+α (α+2n+α) structure, this decay should be enhanced if the parent T=3/2 states are in fact molecular in nature. This would further advance the case for the molecular structure of the ^{11}Be ground state.

The decay of T=3/2 states to, for example, ^8Be+t is isospin forbidden [10], so a study of this decay channel will provide a measurement of the isospin purity of the states assigned to be T=3/2. Further it will allow us to locate T=1/2 states in this nucleus with an α+t+α cluster structure. ^7Li is well known to possess an α+t cluster structure and hence might also be fed strongly from such states. Again the decay to the ground and low-lying states in ^{10}Be might be inhibited due to the lack of structural overlap with the cluster configurations, and the decay to the collection of states at ~6 MeV in ^{10}Be enhanced. Again, similar arguments may be advanced for the decay of T=1/2 states in ^{11}C

Thus the primary aims of the experiment will be to see if that the T=3/2 states are preferentially populated in the $^7Li(^9Be,^{11}B)^5He$ and $^{16}O(^9Be,^{11}C)^{14}C$ reactions, and if subsequently they predominantly decay to final states which contain overlap with the molecular cluster structure. Further, we intend to search for T=1/2 states in ^{11}B and ^{11}C that also have a molecular content. As spins and parities of several of the states in this region are known this measurement does not rely the on angular correlation or distribution measurements to extract spin information, which is complicated in this instance by the use of target and projectile nuclei with non-zero spins. It is, however, hoped that we may be able to extend the systematics of, for example, the T=3/2 states to higher excitation energies and the spin analysis will be possible.

The detection system that we propose to use is based around detectors that have been developed for use with the MEGHA detection system. However, we intend to include an important new element. A previous attempt to study the reaction $^{12}C(^{12}C,^{10}Be)^{14}O$ was unsuccessful due to the lack of channel selection. The measurement was performed using the gas-silicon hybrid detectors to identify the charge of the ^{14}O recoil and strip detectors to detect the decay of ^{10}Be into $^{4}He+^{6}He$. It was hoped that by performing a kinematically over-determined measurement the reaction channel could be resolved. Unfortunately, owing to the small reaction cross section compared with other much stronger processes it was not possible to extract the reaction channel of interest. It is now clear that explicit mass resolution is required in order to perform such measurements effectively. We thus plan to use particle identification telescopes capable of providing mass resolution. These will be formed from a thin (70 μm) silicon detector followed by a (500 μm) strip detector, to resolve multiple hits from the ^{8}Be decay, and backed by a 1cm thick CsI detector to stop the highly penetrating ^{3}H ions and protons. We plan to use four such telescopes housed in the MEGHA chamber, which will be instrumented using the MEGHA data acquisition system. These detectors will be placed ~15cm from the target spanning the angular range 8 to 28 degrees giving a detection efficiency for, e.g., the $^{7}Li(^{9}Be,^{11}B[\alpha,\alpha,t])$ reaction of 5 to 10% (this may be compared with ~2% for the study of the $^{12}C(^{24}Mg,^{12}C\ ^{12}C)$ reaction). Monte Carlo simulations indicate that the resolution with which it will be possible to reconstruct the ^{11}B excitation energy is ~100 keV which is sufficient to resolve the states of interest.

Beam Time Request

The beam time request includes time for the calibration of the detectors and the above measurements. The proposed experimental configuration involves ~150 channels of electronics which takes time to tune and calibrate. Based on past experience this requires of the order of 1 day.

Calibrations

Beam + Energy	Target	Time
^{9}Be 65 MeV	^{197}Au	12 hours (debugging)
^{9}Be 65 MeV	^{197}Au, ^{12}C and ^{27}Al	6 hours
^{9}Be 36 MeV	^{197}Au, ^{12}C and ^{27}Al	6 hours

The experimental measurements will be performed using Li_2O_3 targets of nominal thickness 100 $\mu g.cm^{-2}$. Recent measurements performed at ANU using ^{9}Be beams at ~60 MeV indicate that beam intensities of 30 nA are achievable. The cross sections for exciting the states in $^{11}B$and ^{11}C are unknown, but two nucleon transfer reactions are typically of the order of $mbsr^{-1}$. This would suggest that given the experience of measuring breakup reactions of similar cross sections, that an additional 4 days of beam time would be required for these measurements.

Reaction Measurements

Beam + Energy	Target	Reactions	Time
^{9}Be 65 MeV	Li_2O_3	$^{7}Li(^{9}Be,^{11}B)^{5}He$, $^{16}O(^{9}Be,^{11}C)^{14}C$	4 days

Thus, we request a total of 5 days of beam time for this measurement.

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