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# Search for $^{10}$Be+$^{6}$He Clustering in $^{16}$C

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**Abstract**

The two proton transfer reaction $^{7}$Li($^{18}$O,$^{16}$C)$^{9}$B will be used to populate unbound states in $^{16}$C above the $^{10}$Be+$^{6}$He decay threshold (16.5MeV). A search will be made for states that possess a large overlap with a $^{10}$Be+$^{6}$He cluster configuration by observing their decays to this final state. By measuring the complete kinematics of the reaction, the excitation energies and spins of the $^{16}$C states with this cluster configuration can be determined, as well as any excitations in the daughter nuclei. For states above the thresholds for decay into the $^{10}$Be excited states the relative branching ratios will be measured to give information about the structure of the parent states. Angular correlations between the primary scattering angle and the $^{10}$Be–$^{6}$He breakup angle will be analysed to determine the spins of states identified in the excitation spectrum. These proposed measurements will also allow a comprehensive spectroscopic measurement of $^{16}$C to high excitation.

This measurement forms part of the CHARISSA collaboration's program to study neutron and proton rich light ions ($^{9\to14}$Be, $^{8,9}$B, $^{10,16}$C, and $^{17}$Ne), to compliment work with radioactive beams being carried out by the collaboration at GANIL, and is related to recent work by the collaboration in the search for alpha–chain states in the nuclei from $^{12}$C to $^{28}$Si.

The data from this experiment will form part of a D.Phil. thesis at York.

## 1 Introduction

The Ikeda picture of clustering in light alpha–conjugate nuclei [1] predicts the formation of cluster structures in the vicinity of the thresholds for decay into those particular cluster constituents. Recently, Von Oertzen [2] has considered the corresponding states formed by adding neutrons to the alpha–chain clusters. For example, the $^{9}$Be nucleus is formed by binding a single neutron to the highly deformed $^{8}$Be ($\alpha + \alpha$) two–centre ground state. This nucleus, and others with a $^{8}$Be core (eg. $^{9}$B, $^{10}$Be, $^{11}$Be...), can be studied within the framework of the two–centre shell model [3] because the underlying $\alpha + \alpha$ cluster structure of the $^{8}$Be nucleus has an important impact on the addition of nucleons to the core. By the continued addition of more valence neutrons to the $^{8}$Be core Von Oertzen characterised the beryllium nuclei as

$2\alpha + x$n dinuclear structures. Following on from this he also predicts the existence of trinuclear $3\alpha + x$n molecules in the neutron rich carbon isotopes.

Experimental evidence with which to test these predictions in the more neutron rich isotopes is scarce. However, recently an experiment was performed [4] to locate the $2\alpha$+4n structure in $^{12}$Be with considerable success. Decays to the $^{6}$He+$^{6}$He final state were observed, showing evidence for a rotational band with a large moment of inertia. Decays to the $^{4}$He+$^{8}$He final state were also observed.

The most extreme prediction of the Von Oertzen model is the $3\alpha$+4n isomeric chain state in $^{16}$C (shown schematically in figure 1 in analogy to the Ikeda diagrams), which consists of two covalent bonds defined by a $^{10}$Be dimer (also shown in figure 1). A recent experiment [5] has been performed to search for rotational bands built upon the two–centre $^{10}$Be states. The present measurement is therefore proposed as a natural extension of the $^{10}$Be work.

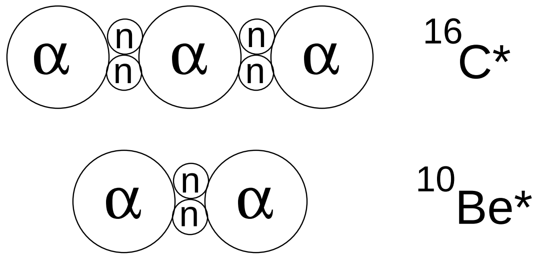


Figure 1: Schematic of multimers built upon alpha–particles covalently bound by valence neutrons in analogy to the Ikeda diagram [1].

This work will link in with previous studies of alpha clustering in light nuclei by the CHARISSA collaboration (see for example [6]), particularly the study of alpha–chain states [7, 8]. The techniques that will be used in the proposed measurement have successfully been used to probe the alpha–conjugate clustering phenomena [9] and can readily be applied to the search for the exotic analogue chain states in the more neutron and proton rich nuclei.

# 2 Experimental Method

The primary reaction, $^{7}$Li($^{18}$O,$^{16}$C)$^{9}$B, requires a minimum $^{18}$O beam energy of $\sim$120MeV to provide the 21MeV of excitation energy needed to reach the cluster states of interest. The detection efficiency for the final state particles after breakup of $^{9}$B$\rightarrow \alpha + \alpha$+p and $^{16}$C$\rightarrow$$^{10}$Be+$^{6}$He increases with beam energy. A beam energy of $\sim$140MeV is available using the 14UD tandem alone or $\sim$155MeV using the tandem plus LINAC booster [10]. The measurement will be performed with the highest beam energy available at the time.

The MEGHA array [11] will be used in this measurement. The $^9$B ejectile is particle unstable and fragments sequentially to $^8$Be+p and finally $\alpha + \alpha$+p. All three $^9$B fragments will be recorded in 16–strip position–sensitive silicon detectors (PSSDs). Although there will be no specific particle identification for these particles, decays from the ground state of $^8$Be can be identified as a sharp peak at 93keV in a plot of the relative energy of two–fold hits in the PSSDs (an example relative energy spectrum is shown in figure 2). Gating on events within this peak and constructing the relative energy spectrum between the identified $^8$Be and a third unidentified particle coincidence (assumed to be the proton fragment) will reveal states in $^9$B. Gating on these $^9$B events will give the equivalent of an isotopic particle identification – this is not usually possible with MEGHA at these energies. The strict requirement of a 3–fold coincidence on one side of the beam will greatly reduce background contamination without the need for specific particle identification, enabling the $^8$Be and $^9$B states to be clearly seen.

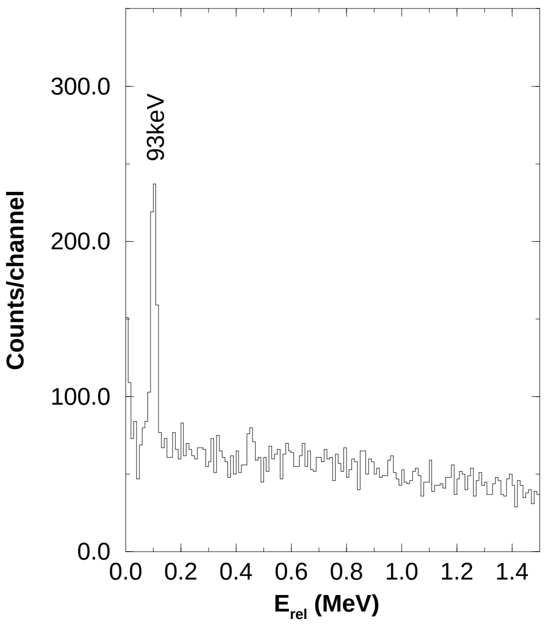


Figure 2: Example plot of the relative energy between two–fold hits in a PSSD. The peak at 93keV corresponds to decays from the ground state of $^8$Be to $\alpha + \alpha$.

Complete measurement of the reaction kinematics can be achieved by recording four of the five final state particles. The missing momentum can be used to reconstruct the energy and angle of the fifth unobserved particle. One or both of the two breakup fragments from the $^{16}$C will be recorded in the gas–silicon particle identification section of MEGHA on the other side of the beam to the $^9$B fragments.

# 3 Beam–time Request

An estimation of the beam time required to successfully extract spin information for the states of interest has been made using data collected in a similar measurement of the reaction $^{12}C(^{7}Li,^{9}B)^{10}Be\rightarrow^{6}He+^{4}He$ [5]. Over a 168 hour (21 shift) period approximately 1500 events per state in the resonant nucleus $^{10}$Be were recorded using a 12enA, 60MeV $^{7}$Li beam incident on a 50$\mu$g/cm$^2$ $^{12}$C target. Monte–Carlo detection efficiency calculations, assuming a similar cross–section for the proposed measurement and a 20enA $^{18}$O beam at 150MeV incident on a 50$\mu$g/cm$^2$ $^{7}$Li target, give an estimation of the rate at which decays from the states of interest are recorded of $\sim$30 counts per hour. At least 2,500 counts are required per state to make a spin measurement – thus it is estimated that this will require approximately 11 shifts to acquire.

A summary of the time required to carry out the proposed measurements is given in table 1. A total of four shifts are requested for beam tuning through the LINAC and detector calibrations.

| Measurement | Beam | Energy (MeV) | Target | Shifts |
|---|---|---|---|---|
| Beam tuning, Calibrations | $^{18}$O | 150 | $^{7}$Li, $^{12}$C, $^{197}$Au | 4 |
| $^{16}$C breakup | $^{18}$O | 150 | $^{7}$Li | 11 |
| TOTAL | | | | 15 |

Table 1: Summary of requested beam–time.

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