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# Excited states in $^6$Li below the $^3$He+$^3$H threshold.

D. Mahboub *et al.*
(for the Charissa Collaboration)

*Department of Physics, University of Surrey, Guildford GU2 5XH, U.K.*
D.Mahboub@surrey.ac.uk

**Abstract**

We aim to explore the excited states in $^6$Li below the $^3$He+$^3$H threshold. Certain classes of levels are predicted by the shell model and three-body models but are not yet observed. The nucleus $^6$Li will be produced using a reaction in which those states should be populated according to recent theoretical calculations. The results will provide a clear test of the theoretical analysis in terms of intrinsic symmetries of the few-body structures in light nuclei. The properties of the 'missing' levels are very important for a better understanding of near drip-line physics and for improving our knowledge about the NN interaction.

## 1 Introduction

Experiments have established a number of excited state levels of mass A=6 nuclei [1]. Only five excited states below 6 MeV are known in the level scheme of $^6$Li (see fig. 1) [1] and no states between 6 MeV and t+$^3$He threshold at $E_x$ = 15.8 MeV have been observed. On the other hand shell model and three-body models predict that nine $0\hbar\omega$ excited states lie below the experimental t+$^3$He threshold. According to a new theoretical study [2], this reflects an intrinsic symmetry in the structure of the nuclear levels, and these states can be populated using three-nucleon transfer. The author explains that these states are populated only when a $^9$Be nucleus transfers one proton and two neutrons to the other partner of the reaction. Briefly, whilst the theoretical predictions can be phrased simply in terms of spectroscopic factors, the arguments in ref. [2] emphasise the contribution from spatial symmetries. In its simplest interpretation, the missing states are expected to have three separate mass centres in a few-body cluster structure, and are accessible from $^9$Be because it has itself a three-centre structure ($\alpha\alpha n$). The investigation of the excited states of $^6$Li, especially between 6MeV and 16MeV, using three-nucleon transfer will be a good test for this theoretical prediction. Furthermore, finding new excited states in this nucleus can constrain more effectively the shell model and three-body models.

As discussed in ref. [2], some tentative evidence for the proposed states has been seen in the three nucleon transfer reaction (p,$\alpha$) on a $^9$Be target. In this case, the final state comprised $\alpha + \alpha + d$ and had contributions from several other processes, as is characteristic of reactions including only very light nuclei.

This proposal uses a three-nucleon transfer from $^{9}$Be, taking advantage of the particular three-centre geometry of $^{9}$Be to populate the relevant excited $^{6}$Li states. We plan then to fully identify the sequential breakup products of the $^{6}$Li, namely a deuteron and an $\alpha$ particle, in two different position sensitive, large area silicon $\Delta$E-E telescopes. These will be placed at forward angles, on opposite sides of the beam direction. These imply the choice of the $^{9}$Be as the projectile, on a fairly light target. This beam has already been shown to be provided with reliability from the 14UD accelerator at Canberra. The channel selection will be carried out by measuring the energy and position of the recoiling nucleus. Because it can be produced in elemental form instead of compound and has been used successfuly at ANU for a $^{11}$B($^{7}$Li,$^{11}$Be) study, we will use a thin target of $^{11}$B. The detection of a third coincidence particle with the correct energy-angle systematics for $^{14}$C will be a good indicator that the specific process of interest has occurred.

## 2 Experimental details

The $^{6}$Li will be produced in the $^{9}$Be + $^{11}$B reaction at a beam energy of 70 MeV using a beam of $^{9}$Be from the 14UD tandem, focussed onto a $^{11}$B self-supporting foil mounted at the forward target position of the MEGHA chamber. Fig. 2 shows the experimental setup proposed for the purpose. The decaying particles from the excited $^{6}$Li will be detected in two different large area telescopes put on opposite sides to each other with respect to the beam direction. The $\alpha$ particle will be detected in a three stage $\Delta$E.E.CsI telescope. The deuteron will be detected in a two stage $\Delta$E.CsI telescope, as will the recoiling $^{14}$C nucleus (in a different silicon strip). The $^{14}$C will be stopped in the first element of the telescope, which is a resistive strip silicon detector (500$\mu$m) giving sub-millimetre resolution in the direction of the 3mm wide strips. Charge and mass discrimination of the deuteron will be achieved by the $\Delta$E-E$_{CsI}$ technique, (which will impose a threshold about 12 MeV for deuteron, for full particle identification). The $\alpha$ particle discrimination is possible by using a thin quadrant Si (70$\mu$m) providing the $\Delta$E signal and a thick Si strip (500$\mu$m) stopping most of the $\alpha$ particles, whilst the most energetic $\alpha$ particles will be completly stopped in the third section, of CsI. Both telescopes will cover an angular range between $8^{o}$ and $22^{o}$. Energy and position information of the three outgoing particles, with unique Z and A identification in two cases, will allow us to identify the channel of interest.

Events in which there is a three stage telescope and two further strips will be recorded, using the MEGHA data acquisition system.

The recoiling $^{14}$C nucleus has an energy around 2.5 MeV in the angular range of interest. The corresponding energy for the coincident particles is spread between 2 MeV and 40 MeV for deuteron and between 20 MeV and 60 MeV for $\alpha$ particle. The angular range of the light charged particles (LCP) is well covered (as shown in fig. 3) for the whole range of the excitation energy of the $^{6}$Li and the recoil angle for the $^{14}$C. We note that the left hand (on the diagram) of the $\alpha$ kinematic particles will be in coincidence with the right hand of the deuteron and the upside with down side, etc.

A similar experimental arrangement was used successfully in September 1999 for a study of $^{9}$Be($^{9}$Be,$^{7}$Be)$^{11}$Be (CH/PROP/ANU/99/09) which is presently in analysis at Surrey (Dr D. Mahboub, Dr W.N. Catford *et al.*). The reconstruction of the three-body Q-value using $\alpha$-d-$^{14}$C detection should give a very clean spectrum in which the $^{14}$C$^{*}$ and $^{14}$C$_{\mathrm{g.s.}}$ events are clearly resolved. It is also reasonable to expect that additional data will be recovered when one of the three final state particles has not been directly observed, albeit with poorer resolution. An example of a Q-value spectrum reconstructed using two of three final state particles (from a 1998 experiment) is shown in fig. 4. The $\alpha$-d angular correlation and the $^{14}$C angular distribution will be analysed to search for spin information.

# 3 Summary and beam request

This proposal is to populate the 'missing' excited states of $^{6}$Li between 6 MeV and t + $^{3}$He threshold, which have never been seen before but are clearly predicted by the shell model and three-body models. For this purpose we use a three-nucleon transfer reaction which is expected on theoretical grounds reliably to populate those states. The experiment will provide a good test of the symmetry arguments developed in ref. [2], in addition to the extra level information obtained. As concluded in ref. [2], these measurements are very important for a better understanding of near drip-line physics and for improving our knowledge about the NN interaction.

Once the experiment is accepted the detector set-up will be optimised by Monte-Carlo calculation taking into account the energy and position resolution. The latest development of the MEGHA capability that includes large-area telescopes will be used to perform this experiment. It is clear that these will have sufficient resolution to give mass (as well as charge) identification for the reaction products entering the telescopes (cf. fig. 5).

We aim for one thousand counts for each state to extract angular distribution information. A thin target of 100$\mu$g/cm$^{2}$ of self supporting $^{11}$B will be used to obtain good energy resolution for the products. The incident beam will be around 3 enA based on previous experience at MEGHA, to avoid acquisition dead time. According to the two-neutron transfer channel $^{9}$Be($^{9}$Be,$^{7}$Be)$^{11}$Be experiment performed last September and according to the theoretical prediction [2] we have estimated 10 shifts for the main reaction study of this experiment. We will need a further two shifts for energy and position calibration of our detectors and tuning the ion source, the accelerator and the beam lines to focus the 70 MeV $^{9}$Be beam on target.

This gives a total request of 12 shifts of beam time for this experiment, including all calibrations:

| Measurement | Beam | Energy (MeV) | Target | Shifts |
|---|---|---|---|---|
| Beam tuning | $^{9}$Be | 70 | none | 1 |
| Calibrations | $^{9}$Be | 70 | Au,C | 1 |
| $^{11}$B($^{9}$Be,$^{6}$Li$^{*}$)$^{14}$C | $^{9}$Be | 70 | $^{11}$B | 10 |
| Target characterisation | $^{16}$O/$^{12}$C | 39.4/29.5 | $^{11}$B | 1 |
| TOTAL | | | | 13 |

# References


[1] F. Ajzenberg-Selove, Nucl. Phys. **A490** (1988) 1.

[2] N.K. Timofeyuk, Nucl. Phys. **A652** (1999) 132.

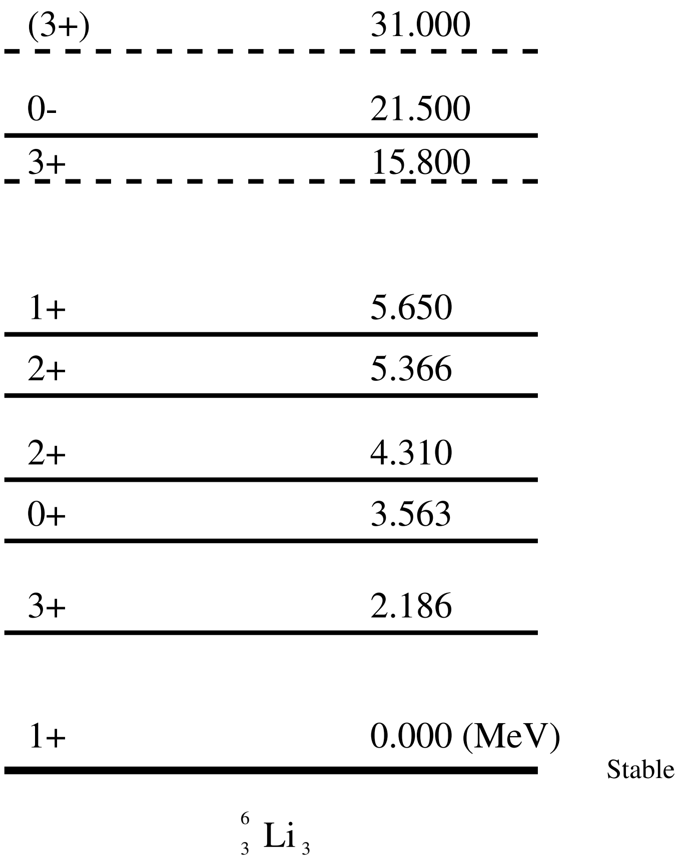


Figure 1: Summary of relevant known levels in $^{6}$Li.

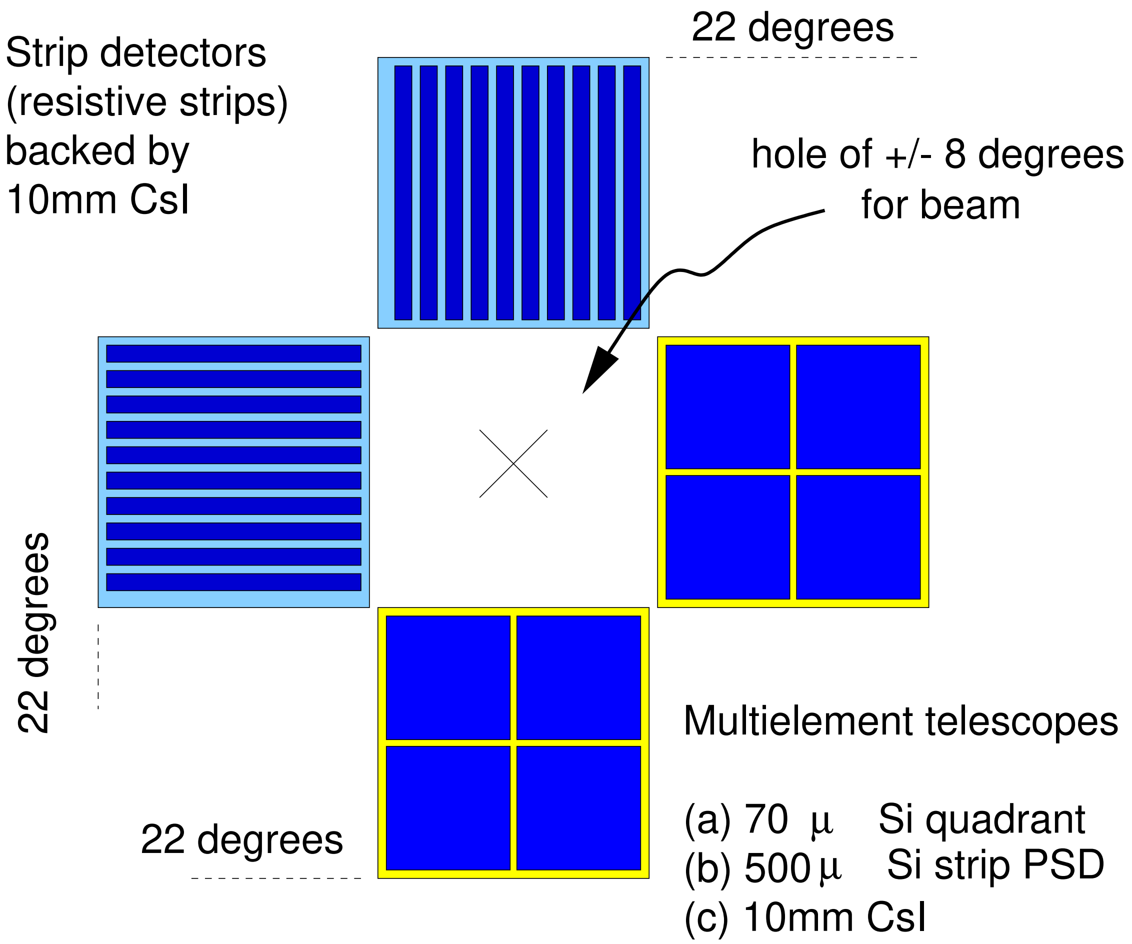


Figure 2: Proposed experimental set-up of detectors around the beam direction. The 16-strip resistive silicon PSD's are shown schematically. The telescopes comprise a 70 $\mu$m thick silicon $\Delta$E detector divided into four quadrants, plus a 16-strip PSD section, finally backed by a 10mm CsI scintillator. These detectors have been employed previously in the MEGHA array.

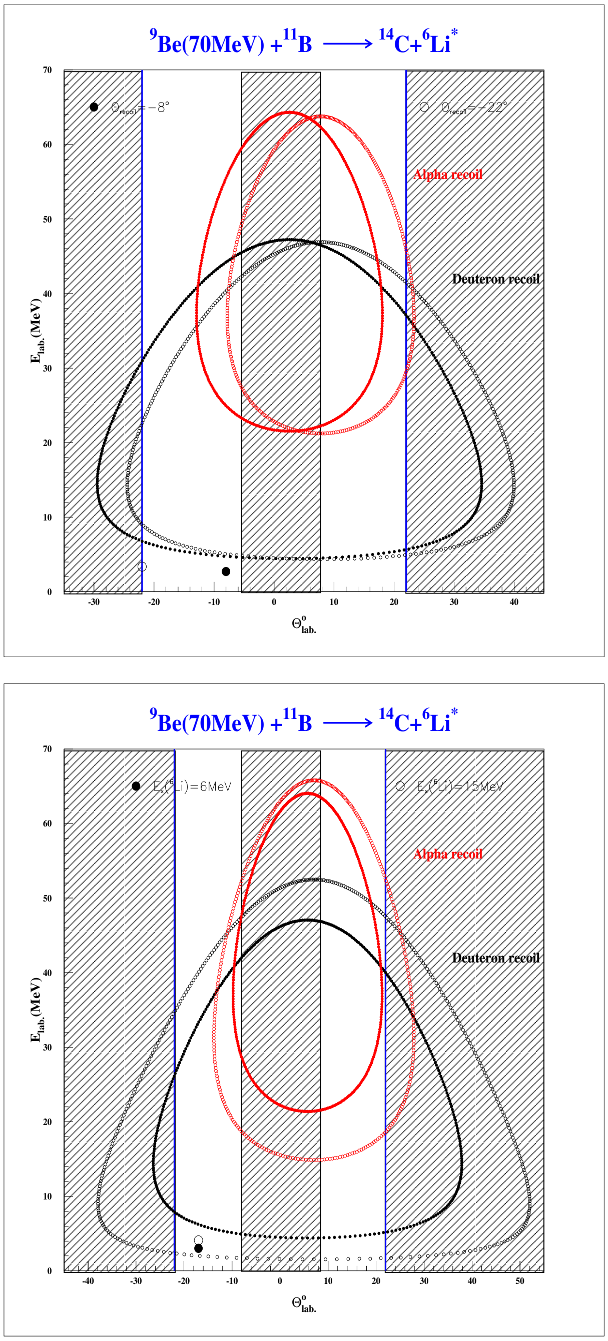


Figure 3: Kinematics of the sequential breakup of $^6$Li excited states for assumed excitations of (a) 10 MeV in the upper panel, and (b) 6 and 15 MeV in the lower panel, for the case of in-plane breakup. The different sets of closed curves in (a) show the breakup for each of two assumed angles for the $^{14}$C ejectile, 8 and 22 degrees. The $^{14}$C ejectile angle in (b) is 17 degrees. The white area indicates the in-plane coverage of the telescopes, and the hatched region is not covered. Whilst this setup is workable, the details would be optimized using Monte-Carlo simulations.

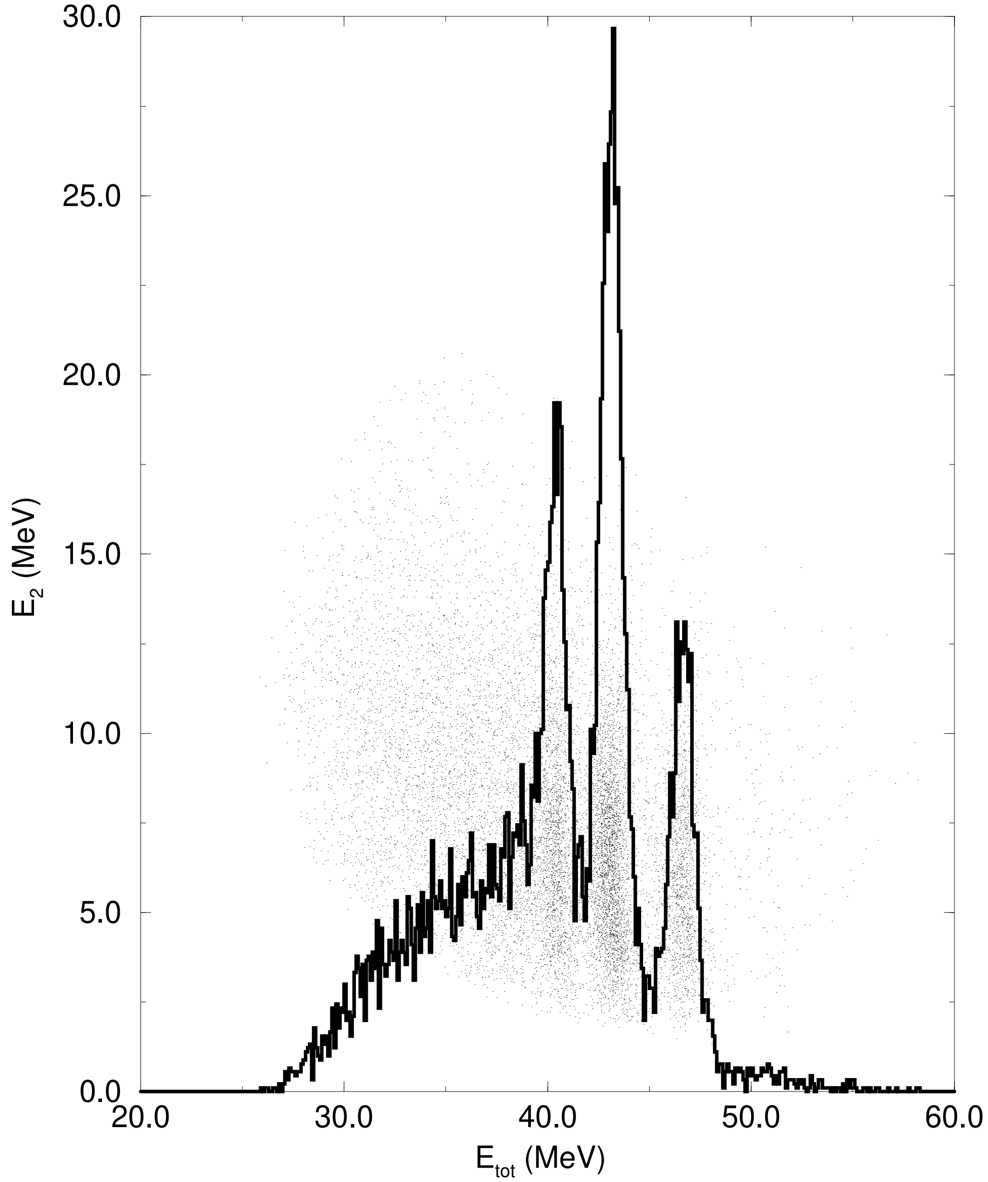


Figure 4: Results from the previous study of ${}^{11}$B(${}^{7}$Li,${}^{7}$Be)${}^{11}$Be$^{*}$ $\rightarrow^{10}$ $Be+n$ showing the three-body Q-value spectrum reconstructed from the energies and angles of the (identified) ${}^{7}$Be and (assumed) ${}^{10}$Be. The two right-most peaks distinguish decays resulting in the $J^{\pi}=0^{+}$ ground state and the $J^{\pi}=2^{+}$ first excited state of ${}^{10}$Be. The scatter plot superimposed on this spectrum shows that the Q-value has no intrinsic dependence on the precise ${}^{10}$Be energy, as required.

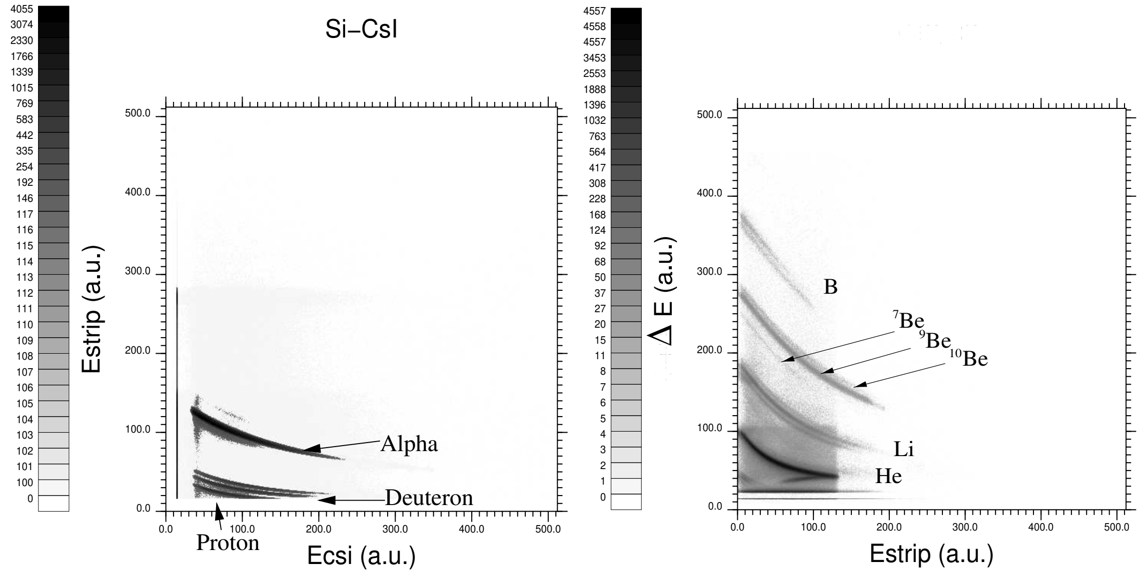


Figure 5: Particle identification results obtained with a similar experimental set-up at MEGHA in our experiment in 1999.