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Resonances in ^{7}Li+^{7}Li scattering?

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Abstract

Measurements are proposed to investigate resonance-like structures observed in ^{7}Li+^{7}Li scattering in the range $E_{lab} = 8$ to 14 MeV. We suggest that if resonances in the compound system are excited in this reaction with a t-α-t-α cluster structure then perhaps only resonances with triton spins coupled to $S = 1$ might have narrow widths. The decay of such resonances to channels with $S = 0$ such as an α-α-α-$2n$ structure may then be inhibited. Such a selection rule could be revealed in measurements of the partial decay widths of these resonances to a number of different channels, including ^{8}Be+^{6}He and ^{10}Be+α. Possible α-α-$2n$ states above 6 MeV excitation in ^{10}Be will also be studied.

1 Introduction

Nuclear structure theories such as the cranked cluster model [1-2] and antisymmetrized molecular dynamics [3-7] provide an alternative description of light nuclei in which evidence for exotic structural configurations has emerged. The existence of α clusters is well established even in ground state bands near $N = Z$, such as in ^{7}Li(t-α) and ^{8}Be(α-α) [8-12]. The appearance of certain cluster components in $N = Z$ nuclei can be understood in terms of particular SU(3) symmetries in the deformed shell model [13]. For $N \neq Z$ excess protons or neutrons may be expected to diminish the cluster structure whereas the reordering of single particle orbits for different N/Z ratios may enhance different cluster components. Indeed there is some evidence of "nuclear molecules" in neutron rich nuclei which are suggested to consist of a multi-cluster core "covalently" bound by valence nucleons, for instance the two-centre "dimers" ^{9}Be(α-α-n) and ^{10}Be(α-α-$2n$) [14-17].

In ^{10}Be evidence for a band of states above 6 MeV excitation with a large moment of inertia comes from a study of the ^{7}Li(^{7}Li,^{10}Be$\rightarrow\alpha^6$He)α reaction at $E_{lab} = 8$ MeV by Soic *et al* [18]. Three states in ^{10}Be were observed at 6.18 (0^+), 7.54 (2^+) and 10.2 MeV. The state at 10.2 MeV was also observed to decay by neutron emission. However, the spin of this state has not been measured and information on the partial decay widths was limited by detector resolution. We have recently initiated a study to address these limitations by attempting to populate these states via triton transfer onto ^{7}Li using the reaction ^{7}Li(^{7}Li,α^6He)α at $E_{lab} = 52$ MeV [19]. These measurements [19] were performed at IReS, Strasbourg using an array of three 500 μm thick 16-strip position sensitive silicon detectors (PSSD's). One of the PSSD's was backed by a CsI scintillator crystal to detect high energy α particles from the primary scattering. The analysis of these data is in progress. This study forms part of a wider programme by the Charissa group to investigate the effect of neutron number on nuclear structure in Be isotopes. The neutron decay of the halo nucleus ^{11}Be has recently been studied at the ANU [20]. Measurements of the symmetric fission of ^{12}Be [21] and an investigation of the ground state breakup of ^{14}Be [22] have been made at GANIL.

Here, we propose to investigate the population of the suggested α-α-$2n$ states in ^{10}Be further. Interestingly, the measurement of Soic *et al* [18] at $E_{lab} = 8$ MeV coincides with an enhancement in the cross section for ^{7}Li(^{7}Li,α)^{10}Be(2^{+}, 3.37 MeV) scattering at 0° [23]. Three resonance-like peaks were observed in these measurements at $E_{lab} = 3.5$, 8 and 14 MeV corresponding to excitations of 28.5, 30.8 and 33.8 MeV in the compound system ^{14}C. Evidence for resonances in this energy region is also suggested by optical model fits to the elastic and inelastic scattering of ^{7}Li+^{7}Li [24]. Note that elastic and inelastic scattering data have revealed the presence of resonances in other systems, for example in ^{12}C+^{12}C scattering which is the subject of another proposal [25]. A very low cross section for scattering to ^{10}Be$_{\mathrm{g.s.}}$ was reported in ref. [23]. This difference in cross section compared to the ^{10}Be(2^{+}) channel is difficult to understand and there must be some particular selectivity in the reaction. We have also submitted a proposal to investigate a possible 4α chain structure in ^{16}O [26]. It is possible that a similar configuration may exist in the form of an α-t-α-t chain in ^{14}C and this could be the origin of the resonance-like structures in ^{7}Li+^{7}Li scattering. Bloch Brink calculations have been performed for arrangements of multi-triton and multi-2-nucleon clusters [27]. Although mixed α and triton cluster calculations are not possible in the model at present, stable configurations of multi-triton and multi-2-nucleon structures have been found [27].

The presence of two triton clusters in a nucleus raises the possibility of states where the tritons are coupled to spin $S = 0$ or $S = 1$. In $A = 6$ nuclei at excitations above the breakup threshold into two 3-nucleon components there are states which are consistent with a 3-nucleon+3-nucleon cluster picture (see figure 1). The two 3-nucleon clusters are coupled to $S = 1$ with odd orbital angular momentum L. Two 3-nucleon cluster structures with $S = 0$ will have a large decay width to both 3-nucleon+3-nucleon and α+2-identical-nucleon channels because of their shell model structure, spin and parity. However, the decay of $S = 1$ states into α+2-identical-nucleon channels may be hindered and they may possibly have narrower widths. This can be understood by considering the possible cluster states in ^{6}He. For an α-$2n$ cluster structure, the lowest lying band is for the nucleons of the α cluster in the $1s$ shell and the $2n$ in the $1p$ shell. According to the "Wildermuth condition" [28] this gives $2N + L \leq 2$ quanta available for relative motion between the clusters. The only possible members of this band are therefore 0^{+} and 2^{+}. The corresponding states in the first excited band of this cluster configuration are 1^{-} and 3^{-}. A low energy configuration with t-t clustering puts 3 nucleons in each of the $1s$ and $1p$ shells and so $2N + L \leq 3$ giving $L = 1$ and 3. States with these orbital angular momenta must be coupled to $S = 1$ to give the correct wavefunction symmetry (antisymmetric under t-t cluster exchange). This gives possible states of 0^-, 1^-, 2^- (twice), 3^- and 4^-. The next highest energy band of states with t-t clustering will have $L = 0, 2, 4$ and $S = 0$ giving 0^+, 2^+, 4^+. Only the unnatural parity t-t $S = 1$ states 0^-, 2^- and 4^- do not have J^π in common with the much lower energy α-$2n$ cluster states. These $S = 1$ t-t cluster states are hindered for decay to the α-$2n$ states and may have narrow widths, since the predominant mean field cluster-cluster interaction is spin independent or diagonal in an $L - S$ (coupled to J) basis. Similar arguments apply to α-t-α-t cluster configurations. States which couple to $S = 1$ may be inhibited for decay to α+α+α+$2n$ channels, whereas $S = 0$ configurations can decay to those channels. According to this picture the decay of the ^{7}Li+^{7}Li resonance-like structures of ref. [23] to $^{10}\mathrm{Be}_{\mathrm{g.s.}}(\alpha+\alpha+2n)+\alpha$ would be expected to be inhibited. The coupling of triton spins to $S = 1$ may be responsible for the narrow widths of the observed structures.

2 Proposed Measurements

We propose to use the MEGHA strip detector array to measure the partial widths for decay to a number of different channels in the energy region of the possible ^{7}Li+^{7}Li resonances, in particular ^{7}Li(^{7}Li,^{10}Be*)α and ^{7}Li(^{7}Li,^{8}Be)^{6}He near $E_{lab} = 8$ to 14 MeV. According to the arguments above, if $S = 1$ resonances are excited in these reactions, final states with $S = 0$ may be inhibited. For example, the channel $^8\mathrm{Be}(\alpha$-$\alpha)+^6\mathrm{He}_{\mathrm{g.s.}}(\alpha$-$2n)$ would be forbidden and may not be observed. Similarly, the decay to α-α-$2n$ states in ^{10}Be should also be hindered. The partial widths for decay to non normal parity states in ^{10}Be(α-t-t) should be larger. These measurements will not only investigate the existence of resonances in ^{7}Li+^{7}Li scattering but allow the further study of possible deformed states in ^{10}Be above 6 MeV excitation. The significant improvement in resolution and detection efficiency of our experimental apparatus as compared to ref. [18] should allow the measurement of spins for these states (in particular for the state observed at 10.2 MeV [18]) using angular correlation techniques [29].

The final state of particular interest in the proposed measurements is α+α+^{6}He (although we will record and analyse data for a number of other channels). The complete measurement of the reaction kinematics can be achieved by recording two of the final state particles in coincidence, one on either side of the beam direction. We propose to detect the recoil-like particle from the primary scattering in coincidence with one of the breakup products of the resonant particle, assuming that this final state results from either the reaction ^{7}Li(^{7}Li,^{10}Be$\rightarrow$^{6}He+α)α or ^{7}Li(^{7}Li,^{8}Be$\rightarrow$$\alpha + \alpha$)^{6}He. The low beam energies prohibit the coincident detection of both breakup products. The missing momentum can be used to reconstruct the properties of the unobserved particle. No explicit particle identification will be employed in the measurements since the low energies of the particles make identification measurements very difficult without severely restricting the sensitive angular range. The analysis techniques that we have developed for breakup reactions should be sufficient to determine the final state and distinguish reactions from the different components of the "^{7}Li" target (LiO on C backing). For instance the Q-value for the reaction

^{7}Li(^{7}Li,α+α)^{6}He (Q = 7.37) is well separated from the possible contaminating reactions ^{16}O(^{7}Li,α+α)^{18}O (Q = 5.22) and ^{12}C(^{7}Li,α+α)^{11}B (Q = 1.39). By assuming the various possible combinations of detected particle masses a momentum analysis can be used to determine the final state [30]. Once the final state has been identified the relative energies between each of the final state particles can be used to construct a "Dalitz plot" [26,31]. The resonant particle decays ^{8}Be$\rightarrow\alpha+\alpha$ and ^{10}Be$\rightarrow^6$He+α can be identified as stripes in the Dalitz plot at fixed relative energies between pairs of particles. The method of particle decay angular correlations can be used to identify the spin of these states [29].

In order to test the method for the measurements proposed here we have generated pseudo-data for a number of reaction channels using a Monte Carlo simulation. This has allowed the optimum detector arrangement to be chosen, namely 6 position sensitive strip detectors covering angles from 17° to 79° in the laboratory. The simulation includes a minimum detection threshold of 3 MeV and an energy resolution of 200 keV. Isotropic breakup of the resonant particles in the centre of mass system is assumed in the simulation. The pseudo-data generated by the simulation have been passed through a sort code and analysed in exactly the same way as real data from the experiment would be i.e. the kinematics of the reaction have been determined from the energy and angle of 2-fold coincidences of unknown mass. Here we have chosen to present results from the analysis of simulated reactions for the lowest beam energy of interest (8 MeV) as this gives the lowest particle energies in the final state. Hence, the detection of particles is most restricted at this beam energy. A Dalitz plot is shown in figure 2 where the reaction channels ^{7}Li(^{7}Li,^{10}Be[7.54,10.2 MeV]$\rightarrow^6$He+α)α and ^{7}Li(^{7}Li,^{8}Be[g.s.]$\rightarrow\alpha+\alpha$)^{6}He have been clearly identified in pseudo-data containing the contaminating reactions discussed above. Angular correlation phase space coverages for the simulated ^{10}Be decays and the chosen detection arrangement are also shown in figure 3. Note that the ^{10}Be$\rightarrow^9$B+n decay channel will be simultaneously recorded in the proposed measurements and our simulations indicate that this can be easily separated from the other channels.

We propose to measure the reactions described above at a number of energies in the range E_{lab} = 8 to 14 MeV. Presently no experimental data are available for these reactions near $\theta_{\rm c.m.}$ = 90° with which to make accurate beamtime usage estimates. We therefore propose to concentrate initially on measurements at E_{lab} = 8 and 14 MeV i.e. at the peak of the resonance-like structures observed in ^{7}Li(^{7}Li,α)^{10}Be(2^+, 3.37 MeV) scattering at 0° [23]. The examination of data online will be used as a guide to the time required to obtain the necessary statistics for a detailed analysis. We request 1 day of beamtime for the measurements at each of these beam energies. Two further days are requested to investigate the reaction at energies away from the resonance-like enhancements and also in the higher energy region $E_{lab} \simeq 14-20$ MeV to test for any further structure in the reaction cross section. In total, we request 5 days of beamtime including 1 day for the necessary detector calibrations.

The ongoing analysis of our recent study [19] at Strasbourg may indicate that supplementary data with higher energy ^{7}Li beams ($E_{lab} = 50-70$ MeV) would be of considerable benefit and a higher priority than measurements in the range $E_{lab} \simeq 14-20$ MeV. The flexibility of the MEGHA system would enable us to make these additional measurements with the minimum of changes to the instrumentation during the requested beamtime.

3 Summary

In summary, we propose to investigate the resonance-like structures previously observed in ^{7}Li+^{7}Li scattering by measuring partial decay widths to a number of channels including ^{8}Be+^{6}He and ^{10}Be+α in the energy region E_{lab} = 8 to 14 MeV (and possibly also at higher energies). These measurements also allow the suggested α-α-$2n$ states above 6 MeV excitation in ^{10}Be to be investigated. 5 days of beamtime are requested for these measurements. This experiment will form part of the thesis work of an EPSRC funded D.Phil student at York (B.G.).

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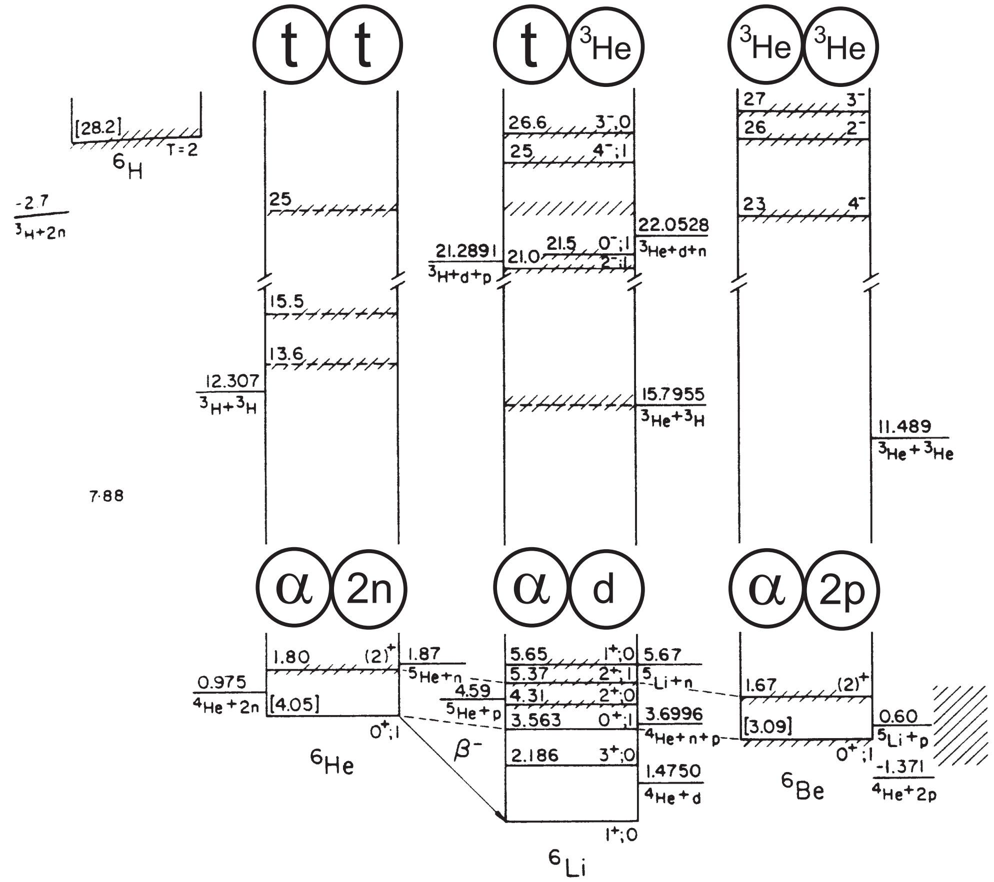

Figure 1: Isobar diagram for $A = 6$ nuclei. Candidates for particular cluster configurations are indicated.

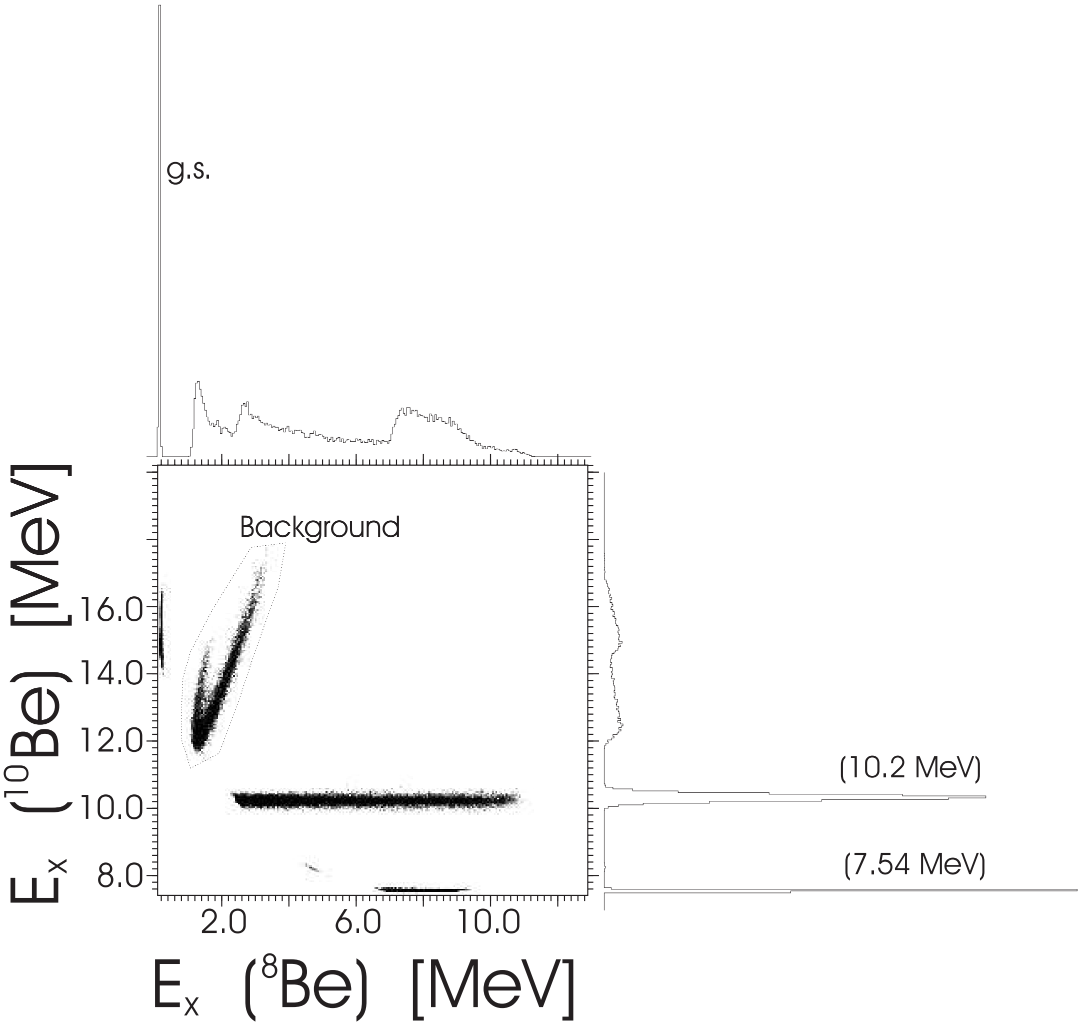

Figure 2: Dalitz plot demonstrating the identification of states in $^{10}\text{Be}\rightarrow{}^{6}\text{He}+\alpha$ and $^{8}\text{Be}\rightarrow\alpha+\alpha$ in pseudo-data using the analysis technique described in the text. The background of misidentified events is well separated from the desired states.

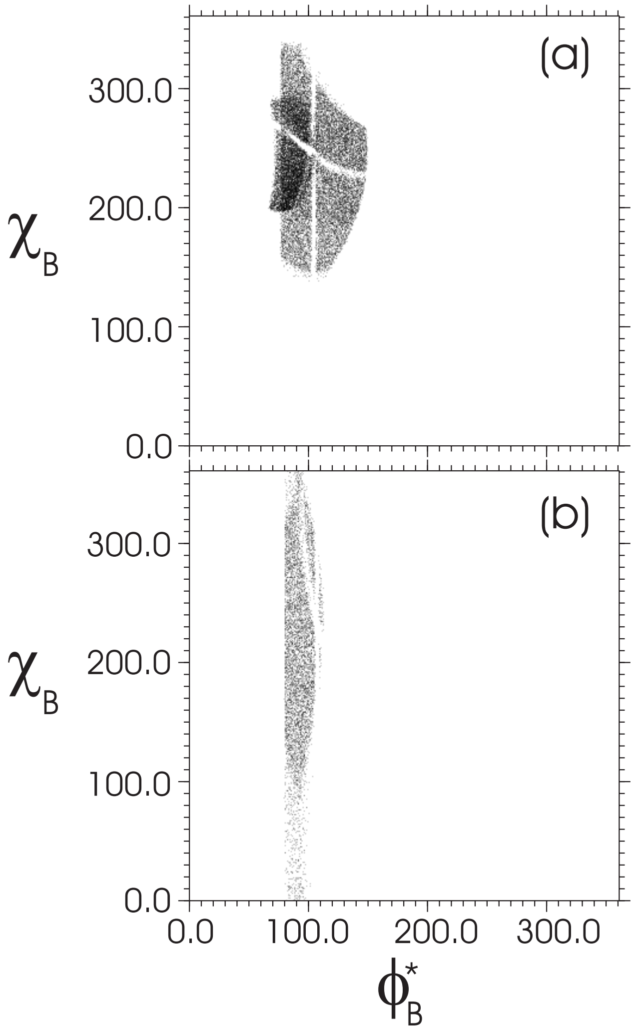

Figure 3: Angular correlation phase space coverages in basel co-ordinates predicted by simulations of the reaction ^{7}Li(^{7}Li, ^{10}Be$\rightarrow$^{6}He+α)α at E_{lab} = 8 MeV for the chosen 6 detector arrangement. Simulation for two excited states in ^{10}Be (a) 10.2 MeV and (b) 7.54 MeV. ϕ^*_B is the primary scattering angle and χ_B the angle describing the subsequent breakup.