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Search for ^{16}O*(10$^+$) near $E_x = 34$ MeV

S.P.G. Chappell and W.D.M. Rae
(for the Charissa Collaboration)

Contact Address: Nuclear and Astrophysics laboratory, Department of Physics, University of Oxford, Keble Rd., Oxford OX1 3RH, U.K.

Abstract

We propose to measure partial widths for the ^{8}Be and α decay of excited states in ^{16}O above 17 MeV using the reactions ^{12}C(^{12}C,^{16}O)^{8}Be and ^{6}Li(^{12}C,^{16}O)d at beam energies near 120 MeV. Results from a previous measurement confirm the existence of ^{16}O(8^+) at $\sim$30 MeV. This is close to the energy predicted for the 4α chain configuration in a coupled-channels cluster model. A search for the 10^+ member of this band predicted at $\sim$34 MeV will be made.

1 Introduction

Many nuclear structure models predict the existence of deformed prolate structures in light $A = 4N$ nuclei [1-7]. The ground state band of ^{8}Be is well known to have an α-α cluster structure [8]. The 7.65 MeV 0_2^+ state in ^{12}C may also have a well developed α-cluster structure [9]. A rotational sequence based on an 8p-8h configuration is predicted in ^{16}O [5-7] by many models. This structure is predicted to have a large moment of inertia consistent with a linear chain configuration of four α particles. The predictions of a coupled-channels cluster model [7] are shown in table 1. A 4α chain is expected to decay predominantly into two ^{8}Be nuclei [7]. Possible candidates for this configuration have been reported above 17 MeV excitation in ^{16}O [10-13] but the association with the ^{16}O 4α chain is not at all clear. In studies of the ^{12}C(α,^{8}Be)^{8}Be reaction [10-12] selected resonances up to a spin of 6^+ were shown to be consistent with a large moment of inertia, but other resonances in the same data set are not. Further evidence for states in ^{16}O that ^{8}Be decay comes from measurements of the ^{12}C(^{16}O,4α)^{12}C reaction [13]. No 8^+ candidate of any 4α chain band has been found in these reactions. Overlapping 8^+ and 9^- resonances have been observed near 30 MeV in the ^{12}C(^{12}C, ^{12}C$_{\rm g.s.}\alpha$)^{8}Be reaction at E_{lab} = 120 MeV [14,15]. It is surprising that an 8^+ state at this excitation which decays to ^{12}C$_{\rm g.s.}$+α has such a narrow width. Also, this resonance is too high in energy to be a member of the $K = 0_2^+$ "kite" (4p-4h) band in ^{16}O. However, it is close to the energy predicted for the ^{16}O 4α chain (8^+) in the coupled-channels cluster model calculations of ref. [7] (see table 1). This model predicts a 10^+ state some 4 MeV higher in energy than the 8^+. There is tentative evidence for a 10^+ near 33 MeV in the data of ref. [15] and also at 34 MeV in the ^{12}C(^{6}Li,d)^{16}O reaction [14,16].

If a 10^+ was found in ^{16}O with the appropriate energy and partial decay widths, the question would arise as to the location and nature of the lower spin members of any chain band. For spins less than 10 $\hbar$ there are a number of local minima in the potential energy surface of ^{16}O [5]. These minima are not well isolated and there could be a large spreading width between configurations in addition to any escape width. Thus many configurations will be mixed in the lower spin region and identification of the chain components is likely to be difficult. In more simple classical terms, unless a chain of well developed α clusters is spinning sufficiently fast the clusters may not be fully aligned and would collapse into a less deformed configuration.

We have recently observed a broad state around 30 MeV with spin 8^+ which decays to ^{8}Be+^{8}Be. This could be the same resonance as observed in ref. [15] which decays to $^{12}\mathrm{C}_{\mathrm{g.s.}}+\alpha$. Only the even spin resonances can be observed for ^{8}Be+^{8}Be decay. The data comes from a previous experiment [17] at ANU, optimised for the measurement of the $^{12}\mathrm{C}(\,^{12}\mathrm{C},\,^{12}\mathrm{C}[3_1^-])\,^{12}\mathrm{C}[3_1^-]$ reaction. The efficient detection of multiple alpha particle final states with good resolution was possible using the newly installed MEGHA strip detector array. Eight 16-strip detectors were used providing angular coverage from 5° to 60° in the laboratory. The $^{12}\mathrm{C}(^{12}\mathrm{C},^{8}\mathrm{Be}_{\mathrm{g.s.}},^{8}\mathrm{Be}_{\mathrm{g.s.}})^{8}\mathrm{Be}_{\mathrm{g.s.}}$ channel at $E_{lab} = 93$ MeV was isolated by detecting 4α particles in the final state and then gating on the $^8\mathrm{Be}_{\mathrm{g.s.}}$ peak in each $\alpha - \alpha$ relative energy spectrum. Undetected particles were reconstructed from the missing momentum. The parenthood of the three $^8\mathrm{Be}_{\mathrm{g.s.}}$ nuclei in these events can be investigated using a "modified Dalitz plot" [19], as presented in figure 1a. In the geometry of the Dalitz plot, an excited state of the parent nucleus (in this case ^{16}O*) is identified as a stripe at a fixed relative energy E_{ij} between the daughter particles parallel to the sides of the triangle shown. The data are confined to a circle of diameter equal to the available energy in the triple $^8\mathrm{Be}_{\mathrm{g.s.}}$ final state. The lack of symmetry in the plot is a result of non random particle order in the data sorting routine. Three states in ^{16}O* have been identified (fig. 1b) at $E_x \simeq 19$, 23 and 30 MeV. The spins of the states have been determined using the angular correlation techniques that we have developed [17,18]. Projections of the measured angular correlation for the state near 30 MeV are compared with Monte Carlo simulations in figure 2. The projection angle and ridge spacing are consistent with 8^+ (see refs. [17,18] for more details of the analysis method). The 6^+ states at 19 and 23 MeV are consistent with those found in previous work [10,11] (but disagree with the 19.3 MeV 4^+ assignment of Freer et al., which may indicate a misassignment in ref [13] or that a different state is populated in that reaction.) Unfortunately, any 34 MeV 10^+ state in these data would lie at the edge of the Dalitz plot in figure 1a and was thus at the limit of sensitivity of the measurement.

2 Proposed Measurements

Our previous results demonstrate that the MEGHA strip array provides us with an efficient tool with which to identify highly excited states in ^{16}O. The "Dalitz" technique described in the previous section can be used to examine the ^{8}Be and α decay of ^{16}O for excitations above 17 MeV. We first propose to confirm the tentative results of ref. [16], where a 10^+ state was claimed to be observed at $E_x = 34$ MeV, using inverse kinematics. The reaction ^{6}Li(^{12}C,^{16}O)d at beam energies around 120 MeV will be used to investigate the possible 10^+ state near 34 MeV. The partial widths for decay to ^{8}Be+^{8}Be, ^{12}C$_{\mathrm{g.s.}}$+α and ^{12}C(0_2^+)+α will be studied. In addition we propose to perform similar measurements for the reaction ^{12}C(^{12}C,^{16}O)^{8}Be near $E_{lab} = 120$ MeV using the technique demonstrated above. The isolation of $^{16}\mathrm{O}\rightarrow^{12}\mathrm{C}(0_2^+)+\alpha$ decays is likely to be more difficult for the ^{12}C target experiment due to the background of direct inelastic scattering events. This experiment is the first step to identifying a 6α chain state [20], since decays of α chain configurations are expected to be predominantly to shorter chains. If candidates for the chain band in ^{16}O are identified it would be interesting to search for resonances in the ^{12}C+^{12}C system involving decay to these states.

The results presented in figures 1 and 2 are from an experiment performed at ANU with continuous running over 2 days using a 10 μgcm^{-2} natural carbon target and an average beam intensity of 20 enA. We therefore estimate that a similar amount of time will be required to make the measurements discussed above. In total a minimum of 5 days of beamtime is requested for these measurements: 2 days with the ^{12}C target; 2 days with the ^{6}Li target and 1 day for the necessary calibrations. The beams requested in this and another two proposals [21,22] require the Linac booster and at least one extra day will be required to optimise the beam tuning.

3 Summary

In summary, we propose to measure the ^{8}Be and α decay of highly excited states in ^{16}O using the reactions ^{12}C(^{12}C,^{16}O)^{8}Be and ^{6}Li(^{12}C,^{16}O)d at beam energies near 120 MeV (A minimum beam energy of 110 MeV is required). 5 days of beamtime are requested for this measurement. A further day is requested to optimise the tuning of beam through the Linac booster. This experiment uses a similar set-up to that described in another two proposals [21,22] and would benefit from running in close succession to those measurements.

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J^π	E_x (MeV)
0^+	—
2^+	22.2
4^+	23.6
6^+	25.8
$\mathbf{8^+}$	**28.7**
$\mathbf{10^+}$	**32.2**
12^+	36.0
14^+	39.9
16^+	43.5

Table 1: Calculations of spin versus excitation energy for 4α chain states in ^{16}O from ref. [7]

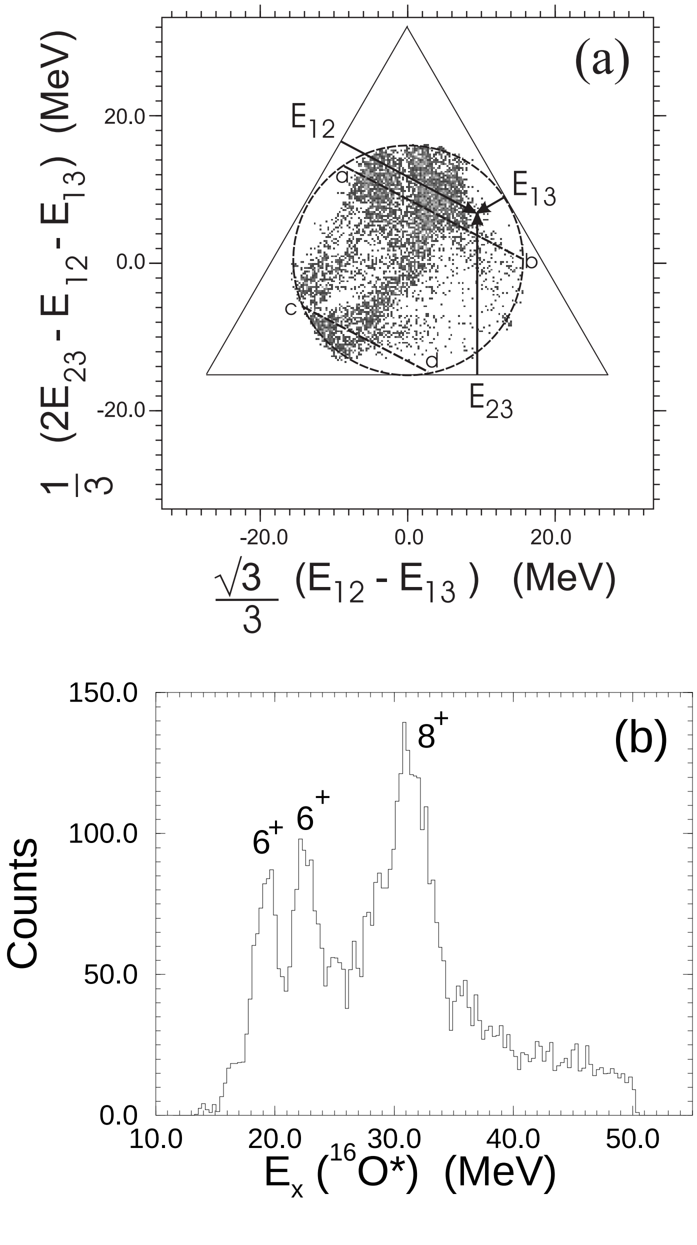

Figure 1: (a) Modified Dalitz plot for the $^{8}\mathrm{Be}_{\mathrm{g.s.}}$+$^{8}\mathrm{Be}_{\mathrm{g.s.}}$+$^{8}\mathrm{Be}_{\mathrm{g.s.}}$ final state. (b) Projection of the region abcd (defined in frame a) onto an axis perpendicular to E_{12}.

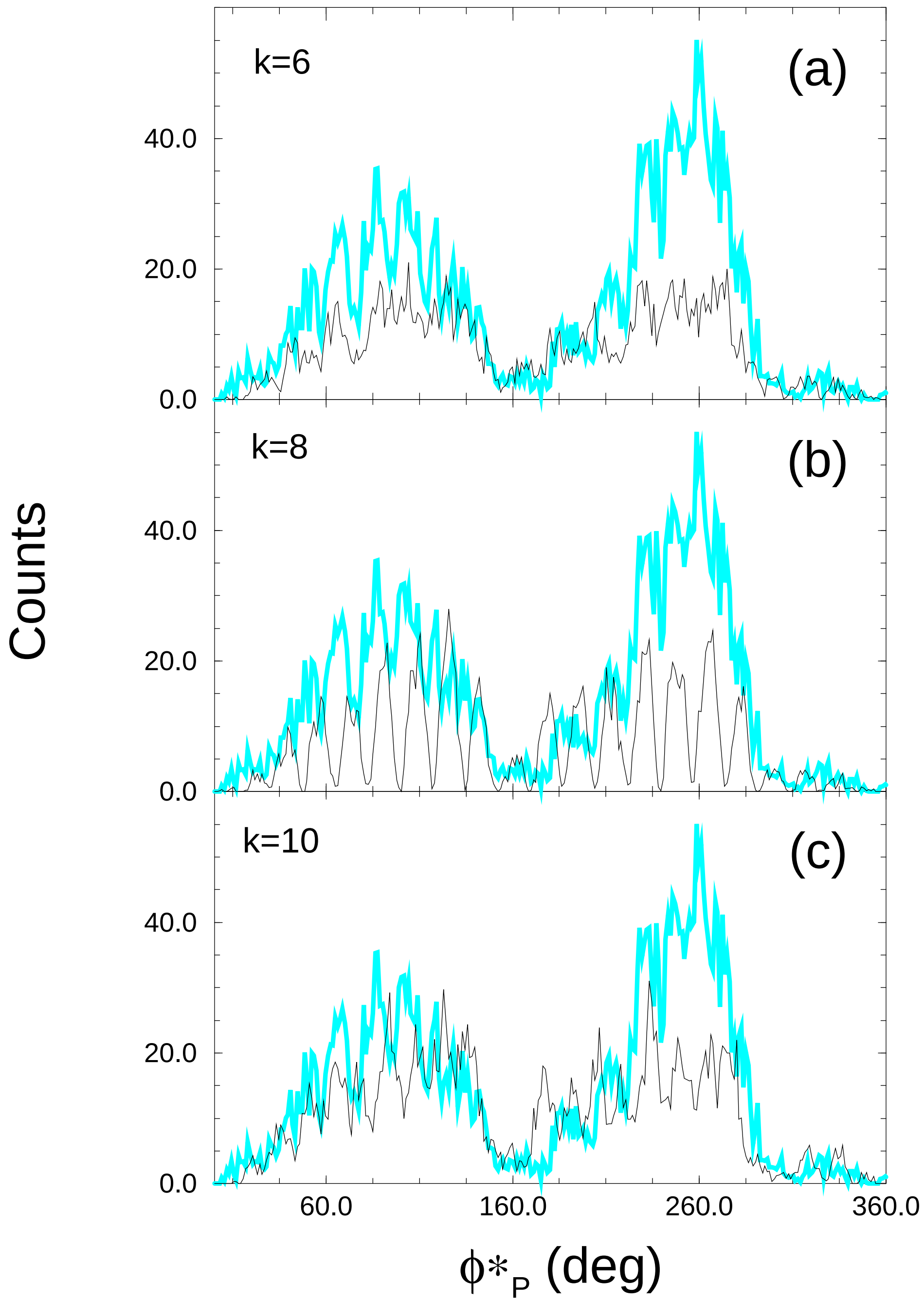

Figure 2: Projected angular correlations for the ^{16}O(30 MeV) state in figure 1. Monte Carlo simulations (thin line) for three consecutive spin values k (and $L' = 10$) are compared with the data (thick grey line) for a projection angle $\theta_P = 127.8°$. The projection angle gives $k = 8.1$ which is consistent with our spin assignment.