Resonances near the 4α threshold through the ^{12}C (^{6}Li,d) reaction

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Abstract

Several narrow alpha resonant ^{16}O states were detected through the $^{12}C(^{6}Li,d)$ reaction, in the range of 12 to 17 MeV of excitation energy. The reaction was measured at a bombarding energy of 25.5 MeV employing the São Paulo Pelletron-Enge-Spectrograph facility and the nuclear emulsion technique. Experimental angular distributions associated with four quasi-bound states near the 4α threshold at 14.30, 14.40, 14.62 and 14.66 MeV of excitation are presented. The natural parity resonance transitions at 14.62 and 14.66 MeV are compared with DWBA predictions.

1 Introduction

Resonances around xα thresholds in light nuclei, as was primarily pointed out by Hoyle in ^{12}C, are recognized important in the production of elements in stars [1]. The main purpose of the research program in progress is the investigation of the alpha clustering phenomenon in (xα) and (xα + n) nuclei through the (^{6}Li, d) alpha transfer reaction [2-5]. In fact, there is scarce experimental information on the subject, in particular associated with odd-even nuclei and with resonant states predicted near the referred breakup thresholds. Alpha resonant states in the nucleus ^{16}O are the focus of the present work. The known 0^{+} state at 15.1 MeV of excitation , that has probably the gas-like configuration of the 4α condensate state with a very dilute density and a large component of α + ^{12}C(Hoyle) configuration [6], is of special concern. On the other hand, the existence of a rotational band with the α + ^{12}C (Hoyle) cluster state structure was recently demonstrated by Ohkubo and Hirabayashi [7]. In order to explore this region of renewed interest, measurements of the $^{12}C(^{6}Li,d)^{16}O$ reaction up to 17 MeV of excitation at an incident energy of 25.5 MeV, have been performed employing the São Paulo Pelletron-Enge Split-Pole facility and the nuclear emulsion detection technique.

2 Experimental Procedure

A 25.5 MeV ^{6}Li beam of the São Paulo Pelletron accelerator impinged a uniform and clean ^{12}C target. Two targets with 112 and 30 μg/cm^2, respectively, were used in the data acquisition. The deuterons emerging from (^{6}Li,d) reaction were momentum analyzed by the magnetic field of the Enge-Spectrograph and detected in emulsion plates (Fuji G6B 50 μm thick). Spectra associated with six scattering angles, from 5° to 29° in the laboratory frame, each one along 50 cm of the focal surface, were measured from 10 MeV up to 17 MeV excitation energy. After processing, the plates were scanned in strips of 200 μm and the spectra were obtained, displaying the number of tracks per strip versus the position along the focal plane. Several narrow resonances with a quasi-bound behavior embedded in the continuum were detected and the resolution of 30 keV and 15 keV, for the respective

targets, allowed for the separation of doublets not resolved before [8, 9]. Figure 1 displays, for further discussion, the region around the 4α threshold in the measured position deuteron spectrum associated with the scattering angle of 5°. The J^{π} and excitation energies in MeV of the detected states, taken from Tilley et al. [10], are indicated.

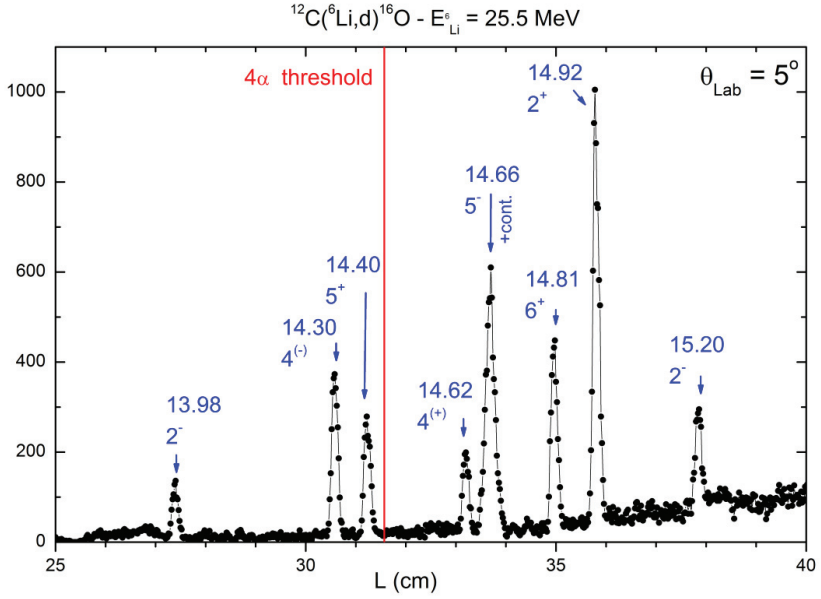

Figure 1: Position deuteron spectrum, corresponding to the indicated scattering angle, near the 4α threshold. The J^{π} and excitation energies in MeV of the detected states, taken from Tilley et al. [10], are indicated.

The relative normalization of the spectra and the absolute scale of the cross sections were, respectively, referred to the beam total charge collected in each run and to optical model predictions for elastic scattering measurements, in the same target and under similar conditions.

3 Results and Discussion

One step alpha transfer finite-range DWBA calculations, in this preliminary analysis, were performed to describe mainly the shape of those experimental angular distributions associated with resonances excited by a dominant direct process.

The optical model used for the entrance and exit channels, in the DWBA calculations, employed the global parameter sets of Cook [11] and of Daehnick et al. [12] respectively. The binding potential of Kubo and Hirata [13] was taken for the α + d description of ^{6}Li and, although resonant, the states under consideration were assumed to be bound by 100 keV in a Woods-Saxon binding potential (r_0 =1.25fm, a = 0.65 fm). Relative to the ^{12}C core, G [14] values 8 and 9 were considered, respectively, for positive and negative parity alpha states.

The experimental angular distributions, not previously reported, associated with four alpha narrow resonances, near the 4α threshold (14.44 MeV) at 14.30, 14.40, 14.62 and 14.66 MeV of excitation energy (see Fig. 1), are presented in Fig.2 [10]. The cross section uncertainties are relative

and the natural parity resonance transitions at 14.62 and 14.66 MeV are compared with DWBA predictions.

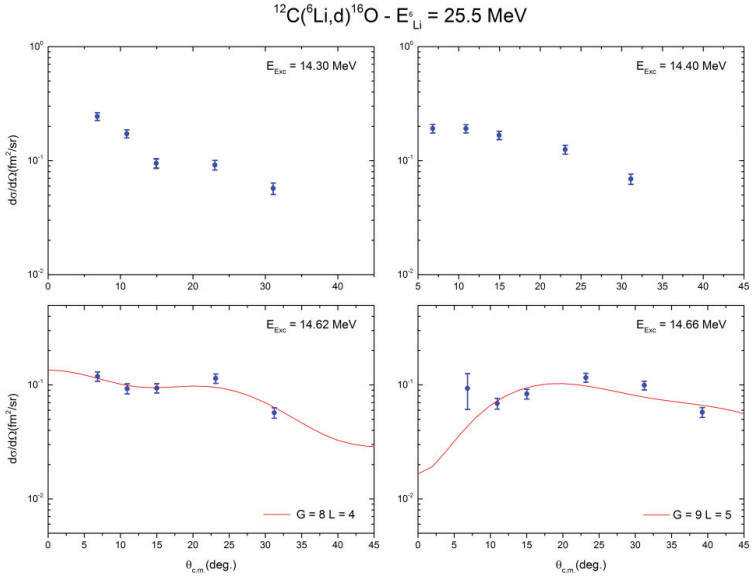

Figure 2: Experimental angular distributions. The DWBA predictions are shown for natural parity resonance transitions.

This preliminary DWBA analysis shows important direct contribution associated with the resonance at 14.62 and 14.66 MeV. It is to be noted that for the first one the positive parity is confirmed.

Note that the doublet resolved in the present work just above the 4α threshold, associated with $J^{\pi} = 4^{(+)}$ and 5^{-} at 14.62 and 14.66 MeV excitation energies, respectively [10], was also observed by Ames [15] in alpha elastic scattering on ^{12}C excitation function. The 5^{-} resonance was interpreted as a member of the $K^{\pi}=0^{-}$ alpha cluster band [10,15]. On the other hand, Wheldon et al. [9] detected through ^{12}C (^{6}Li,d) reaction at a higher incident energy only one state at 14.6 MeV associated with a strongly populated broad resonance which decays to the ^{12}C ground state. The unnatural parity resonances observed in the present work at 14.30 and 14.40 MeV were also reported and decay to the 2_1^{+} ^{12}C state [9] .

In the region of the 0^{+} state at 15.1 MeV of excitation that has probably the gas-like configuration of the 4α condensate state[6], was detected only one state, most like the state $J^{\pi} = 2^{-}$ at 15.20 MeV, as also indicated by Wheldon et al.[9].

4 Conclusions

The $^{12}C(^{6}Li,d)^{16}O$ reaction, measured at a bombarding energy of 25.5 MeV, populated several narrow resonances in ^{16}O from 12 to 17 MeV of excitation. Around the 4α threshold, the discrimination of at least three doublets, allowed by the excellent energy resolution of the data, also revealed a quasi-bound behavior of eight resonant states. The experimental angular distributions, not previously measured, associated with the resonances at 14.30, 14.40, 14.62,

and 14.66 MeV of excitation are presented and compared for the natural parity states with DWBA predictions. A parity doubt is resolved and new information in this region of interest is provided. The present work is in progress and further analysis is undergoing.

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