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THE $Li^6(p, \alpha)He^3$ REACTION

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Abstract: The $Li^6(p, \alpha)He^3$ reaction has been studied up to 5 MeV proton energy. The excitation curve and angular distributions were measured from 2.0 to 5.0 MeV proton energy in steps of about 100 keV. The possible existence of a positive parity state of Be^7 around 4.0 MeV proton energy is indicated.

1. Introduction

The $Li^6(p, \alpha)He^3$ reaction has been studied from 0.6 MeV to 2.9 MeV proton energy by Marion *et al.* [1]) and from 100 to 300 keV by Khanh *et al.* [2]). Marion *et al.* [1]) measured the excitation function at four angles and deduced the angular distribution for the energy region from 0.6 MeV to 2.9 MeV. They found two resonances in the excitation curve, one around 1 MeV proton energy and the other around 1.85 MeV proton energy. The first they attributed to an S wave state with $J = \frac{3}{2}^+$ and the other to a P wave state with $J = \frac{5}{2}^-$. In this energy region, they also observed a non-resonant background which they subtracted to fit the results with resonance theory. The $\frac{3}{2}^+$ state occurs around 6.5 MeV excitation in Be^7 while the $\frac{5}{2}^-$ around 7.8 MeV excitation. The latter state is the mirror state of the 7.68 MeV state in Li^7 observed in the $Li^6(n, \alpha)H^3$ reaction [3]). Johnson *et al.* [3]) give arguments from the excitation curves of the total cross-section of Li^6 for neutrons and from the $Li^6(n, \alpha)$ H^3 reaction, that the 7.68 MeV state is most probably a $\frac{5}{2}^-$ state formed by P wave neutrons.

The assignment of positive parity to the 6.5 MeV state in Be^7 observed by Marion *et al.* [1]) was motivated by the existence of odd Legendre polynomial terms in the angular distribution. They argued on the possibility of an s-state for this level, since a d-state would not yield the cross-section observed. The $\frac{3}{2}^+$ assignment then results from consideration of the $P_1(\cos\theta)$ interference term in the angular distribution.

Subtracting the non-resonant background both in the $Li^6(n, \alpha)H^3$ and $Li^6(p, \alpha)He^3$ reactions, one finds on the above assumptions, that the 6.5 MeV level has a large He^4 reduced width compared to Wigner limit while the 7.8 MeV level has a large nucleon reduced width.

Recently Tombrello *et al.* [4]) observed the 6.5 MeV level in the elastic scattering of He^4 by He^3 and their results definitely rule out the possibility of a positive parity

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state. Their phase shift analysis indicates that this is probably an $f_{\frac{5}{2}}$ state, though an $f_{\frac{7}{2}}$ state cannot be absolutely ruled out. Also they did not observe the 7.8 MeV level in the scattering experiment but it occurs in the $He^4(He^3, p)Li^6$ reaction.

In this paper we present results on the $Li^6(p, \alpha)He^3$ reaction from 1.9 MeV to 5.0 MeV, in order to investigate the possible existence of a higher positive parity state responsible for the odd Legendre polynomial terms in the angular distribution observed by Marion *et al.* [1]) and by Khanh *et al.* [2]).

2. Experimental Method

The $Li^6(p, \alpha)He^3$ reaction was studied from 1.9 MeV to 5 MeV proton energy using the Van de Graaff machine at Saclay. The targets were 99.6% enriched Li^6 metal targets deposited on 10 $\mu g/cm^2$ carbon backings. The Li^6 metal was evaporated onto the backing and allowed to remain in air for sufficient time in order to obtain the stable hydroxide. The thickness of the Li^6 in the targets was of the order of 10 $\mu g/cm^2$.

The scattering chamber had a movable top which carried the target and the detector and which could be continuously rotated under vacuum. Since one could observe at any angle both the reaction products He^4 and He^3, it is only necessary to measure the angular distribution from 0° to 90°. The angular distribution in the backward angles for any one of the two emitted particles could then be deduced using the dynamics of the reaction, from the angular distribution in the forward angles of the other particle.

The excitation curves from 1.9 MeV to 5.0 MeV proton energy were obtained for angles from 20° to 80° in the laboratory system in steps of around 5° in most cases. The energy steps used were from around 50 to 120 keV. A solid state counter was used as particle detector. Since the He^4 pulses started overlapping with the proton pulses in the higher energy region for angles around 80°, the solid state detector was so chosen that it had a depletion width corresponding to around 3 MeV protons. This helped to separate the He^3 pulse from the proton pulse at higher energies.

A solid state detector fixed at 90° served as monitor. Only the He^3 pulses of the monitor were used for normalising the data. This was due to the difficulty of separating the He^4 pulse from the proton pulse at 90°.

Three different slit diameters were used to enable measurements in the forward angles. The slits were calibrated at a fixed angle, the counts being normalised with respect to the monitor. This enabled the measurements to go down to 20° with a dead time less than 3%.

3. Results

The excitation curves obtained from 1.9 MeV to 5 MeV for the various angles were corrected for solid angle and normalised to the monitor, and the angular distributions in the CM system were obtained from them and fitted to the equation

$$W(\theta) = A_0 \left[1+\sum_{n=1}^{4} A_n P_n(x)\right]$$

by the method of least squares on IBM 7090. Here $P_n(x)$ is the Legendre polynomial of order n, where $x = \cos\theta$. These angular distribution curves for various incident proton energies are shown in fig. 1. The solid curves in these figures are the least-squares fit described above.

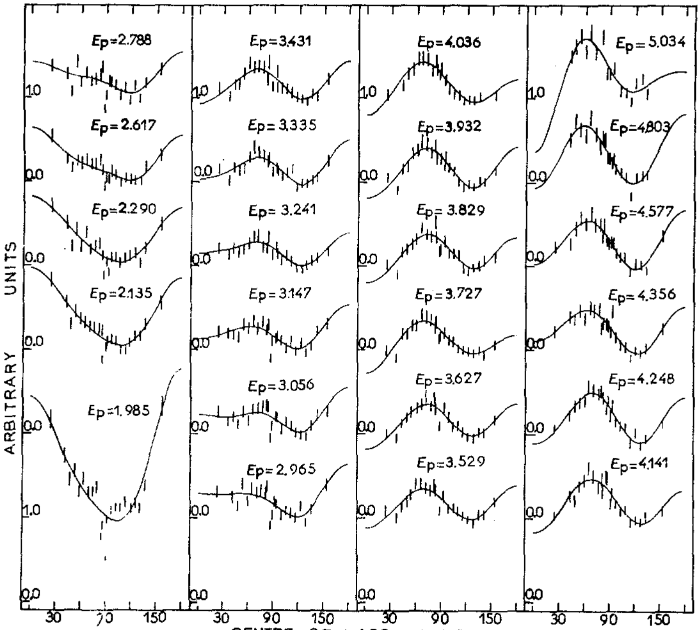

Fig. 1. Angular distribution of He^3 from the $Li^6(p, He^3)\alpha$ reaction for various incident proton energies. The solid curves represent least-squares fit to the data.

The coefficient A_0 in the above expression would yield the excitation curve as a function of incident energy. We converted this to absolute cross-section as follows. Using a gas scattering chamber, Tombrello *et al.* [4]) measured the absolute cross-section for the inverse reaction $He^4(He^3, p)Li^6$ at the laboratory angle of 30° for various energies. Using our A_n coefficients and the principle of detailed balance, we normalised our excitation curve to the data of Tombrello *et al.* over the same range of energy of excitation as used by them. It must be remarked that over this range of energy, the two results agreed within experimental error in relative values. As mentioned by Tombrello [5]), the cross-section obtained by Marion *et al.* [1]) differs from their value by a constant normalisation factor. In fig. 2 are shown our results for total cross-section obtained as described above. The dots in the figure are the data of Marion *et al.* [1]), while the crosses are the same data normalized to our curve, the normalisation factor being around 1.2.

Figs. 3-5 show the A_1, A_2, A_3 and A_4 coefficients defined above. The crosses in these figures are from Khanh *et al.* [2]) while the dots are from Marion *et al.* [1]). The agreement with these authors is reasonable.

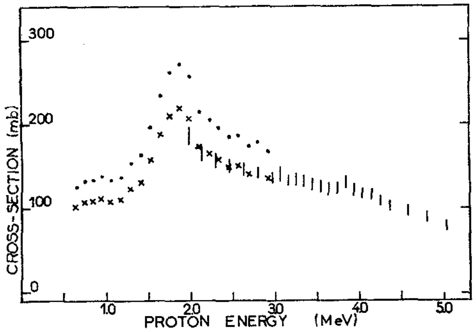

Fig. 2. Total cross-section curve for the Li^6(p, He^3)α reaction. The dots represent the data of Marion *et al.* [1]). The crosses represent the data of Marion *et al.* normalized to our data as explained in the text.

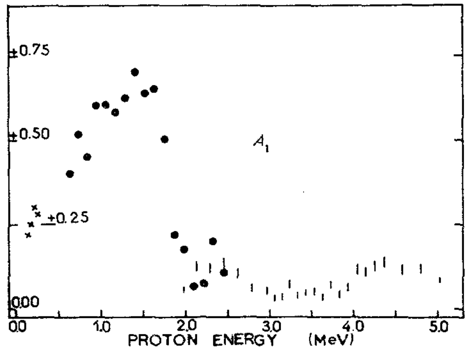

Fig. 3. Variation of A_1 coefficients with incident proton energy. The dots represent the data of Marion *et al.* [1]) and the crosses represent the data of Khanh *et al.* [2]).

If the assignment for the 6.5 MeV and 7.8 MeV states in Be^7 are both taken to be $\frac{5}{2}^-$ as suggested by Tombrello *et al.* [4]), then the data show that a positive parity state should exist at a higher energy to explain the odd terms in the expansion in terms of Legendre polynomials. Our excitation curve shows that such a state, if it exists at all, should be very broad and hence could not be a (nucleon-mass 6) system. Recently McCray [6]) observed a state, probably with positive parity, in the Li^6(p, p)Li^6 reaction. Perhaps this state is not the same as the one indicated by our results, since it is difficult to understand why a broad state with possibly a large He^4 width as is required by our data should appear in the proton scattering on Li^6. It is quite possible that there are two positive parity states, one a nucleon state and the other a He^4 state. Also if one looks at the theoretical predictions of Meshkov *et al.* [7]), one sees that this region of Be^7 (or the mirror system Li^7) is fairly complex. The 6.5 MeV $\frac{5}{2}^-$ state possibly has the configuration $f_{\frac{5}{2}}$ and the 7.8 MeV state the configuration $p_{\frac{5}{2}}$. They also predict between 8 and 11 MeV excitation, $p_{\frac{3}{2}}$, $p_{\frac{1}{2}}$ and $d_{\frac{7}{2}}$, $d_{\frac{5}{2}}$ states. It is possible that the positive parity state in question in this work is one of the two d states. Detailed resonance theory calculations have been undertaken to resolve these questions.

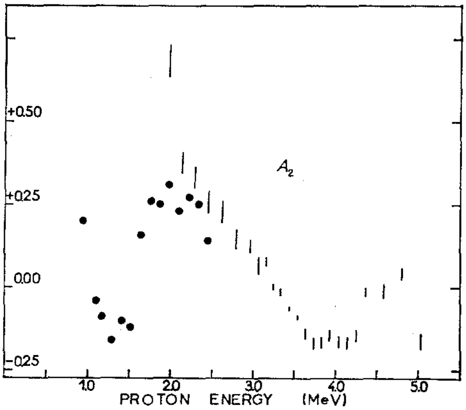

Fig. 4. Variation of A_2 coefficients with incident proton energy. The dots represent the data of Marion *et al.* [1]).

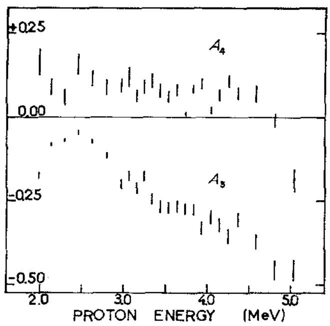

Fig. 5. Variation of A_3 and A_4 coefficients with incident proton energy.

Lastly one cannot exclude some contribution from direct interaction. We could only state that the variation of the A_n coefficients with energy as observed by us as well as the low L values involved in the Legendre polynomial expansion indicate that resonance contribution to the reaction is the major one.

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