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COHERENT PION PRODUCTION IN $^{6}Li(^{3}He,\pi^{+})^{9}Be$ AND $^{10}B(^{3}He,\pi^{+})^{13}C$ CLOSE TO THRESHOLD

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Abstract

The energy dependence of the $^{6}Li(^{3}He,\pi^{+})^{9}Be_{g.s.}$ reaction at $\theta_{lab} = 20°$ has been studied for $T_{^{3}He} = 235, 260, 270$ and 283 MeV and at 40° and 55° for 235 and 283 MeV. A semi-phenomenological model reproduces the shape of the angular distribution and the order of magnitude of the cross section but predicts a too sharp energy variation. Experimental results on $^{10}B(^{3}He, \pi^{+})^{13}C_{g.s.}$ at $20°_{lab}$ for 260 and 283 MeV are of a similar size.

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In our first $(^3He,\pi^+)$ measurements[1)] close to threshold carried out on a cryogenic ^3He target we found sizeable cross sections for the $^3He(^3He,\pi^+)^6Li_{g.s.}$ and $^6Li_{2.18\ MeV}$ and these have been explained semi-quantitatively in terms of a model which uses data on the elementary reaction $^1H(^3He,\pi^+)^4He$ as input[2)]. An additional experiment on $^4He(^3He,\pi^+)^7Li$ yielded cross sections of a similar magnitude and showed the description of the reaction mechanism to be reasonable[3)]. An alternative model[4)], which assumes that an initial Δ excitation propagates in the final nucleus and decays by emitting the pion, has also given a plausible explanation of the $^3He(^3He,\pi^+)^6Li$ case but has not yet been extended to heavier nuclei.

An investigation of the reaction mechanism and a search for nuclear structure effects should be carried out with heavier targets and, as a first step, we have studied the cases of ^6Li and ^{10}B. Preliminary results[5)] indicated that the experiment would be much harder than the corresponding $^{3,4}He$ ones, with cross sections a factor of 1000 smaller. A similar conclusion could be drawn from the higher energy measurements on the $(^3He,\pi^-)$ reaction on ^6Li and ^9Be targets[6)] which revealed cross sections to possible discrete states of the order of pb/sr. Also from a theoretical point of view the nuclear structure complications make calculations on these nuclei far more uncertain though crude estimates do exist for the ^6Li target[7)].

The experimental arrangement[8)] consisted of a small QQD electromagnetic device. Pions were focussed onto a thin plastic scintillator by the quadrupole doublet and analysed in a 180° spectrometer. Two wire chambers, triggered by a four-fold coincidence of signals in plastic scintillators, were used to localise the pions in the focal plane. Two time-of-flight measurements were recorded with the chamber information and used to reduce the background. This overdetermination was not necessary for the cryogenic target experiments but proved very useful in the present cases because of the low counting rates. The solid angle of 6.2 ± 0.2 msr was also a crucial feature enabling these small cross sections to be measured.

The experimental spectra obtained for the $^{6}Li(^{3}He,\pi^{+})^{9}Be$ and $^{10}B(^{3}He,\pi^{+})^{13}C$ reactions at 260 MeV and a laboratory production angle of 20° are presented in figure 1. The targets were kept thin (47 ± 2 mg/cm² and 23.5 ± 1 mg/cm² for ^{6}Li and ^{10}B respectively) in order to maintain an energy resolution of about 1.5 MeV on the final nuclear state. This width is mainly due to the difference in the energy losses of the ^{3}He and π^{+} in the targets. The beam intensity was limited to 400 nA because of the photomultiplier counting rates so that each spectrum required a 24 hour run. In each case the ground state is clearly resolved but even rough estimates of the production cross sections for the groups of excited states are made impossible by the geometrical loss of efficiency.

The experiments have been carried out at a laboratory angle of 20° for four different energies (235, 260, 270 and 283 MeV) on ^{6}Li. In addition measurements at 40° and 55° for the two extreme energies were performed to give information on the shape of the angular distribution. For the ^{10}B target data was only taken at 260 and 283 MeV and then just at 20°. The results are presented in figures 2 and 3 having been corrected for pion decay, muon contamination, nuclear reaction losses and detector efficiency. There is an overall normalisation uncertainty of ± 30% in addition to the statistical and background contamination effects which are shown in the error bars.

The most striking feature of the results is the low value of the cross sections obtained for the ^{6}Li and ^{10}B targets (a few tens of pb/sr) as compared to those found for the ^{3,4}He targets (a few tens of nb/sr). However there is almost no decrease observed between the ^{6}Li and ^{10}B. A crucial test of any theoretical model is to reproduce this drop of three orders of magnitude.

In the observed region the cross sections decrease smoothly with increasing angle or energy, i.e. with increasing momentum transfer.

In the theoretical model of Germond and Wilkin[2)] the reaction proceeds through a ^{1}H(^{3}He,π^{+})^{4}He mechanism on one of the protons in the target nucleus and in a process such as ^{6}Li(^{3}He,π^{+})^{9}Be there will be one neutron and one alpha particle as spectators. Cluster model wave functions are taken for ^{6}Li $(\alpha + p + n)$ and ^{9}Be$(\alpha + \alpha + n)$. The input amplitudes are deduced from the Orsay measurements[8)] at low energies and from the charge-symmetric inverse reaction ^{4}He(π^{-},n)^{3}H at higher energies[9)] and the results of the calculations[10)] are shown in figures 2 and 3.

The shapes of the angular distributions shown in figure 2 are encouraging and the model also reproduces the order of magnitude of the cross sections but it is clear from figure 3 that it predicts too steep a dependence in energy. This may be due to the lack of distortion effects in the calculation or the use of harmonic oscillator wave functions to describe the cluster models since these do not have enough high momentum components. The dramatic fall between ^{3,4}He and ^{6}Li seems in this model to be mainly due to the struck proton in the target nucleus being in the p rather than s-shell, the increased nuclear radius but also a kinematic effect. For a given incident ^{3}He energy the energy of the produced pion increases significantly with target mass and cross sections tend to decrease with increasing pion energy.

We hope to carry out further tests on the $(^3\mathrm{He},\pi^+)$ reaction near threshold to see if we can find nuclei where structure effects can enhance the cross section. This would provide further insight into the reaction mechanism as also would measurements of other three-nucleon transfer reaction such as (α,p) at the same high momentum transfer.

It is a great pleasure to acknowledge the help of all the Orsay Synchrocyclotron crew who have made this experiment possible. We are also indebted to J.F. Germond and C. Wilkin for stimulating discussions and the explicit calculations presented here.

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FIGURE CAPTIONS

Figure 1 : Experimental $^{6}Li(^{3}He,\pi^{+})^{9}Be$ and $^{10}B(^{3}He,\pi^{+})^{13}C$ spectra corresponding to a 260 MeV incident energy and measured at $20°_{Lab.}$.

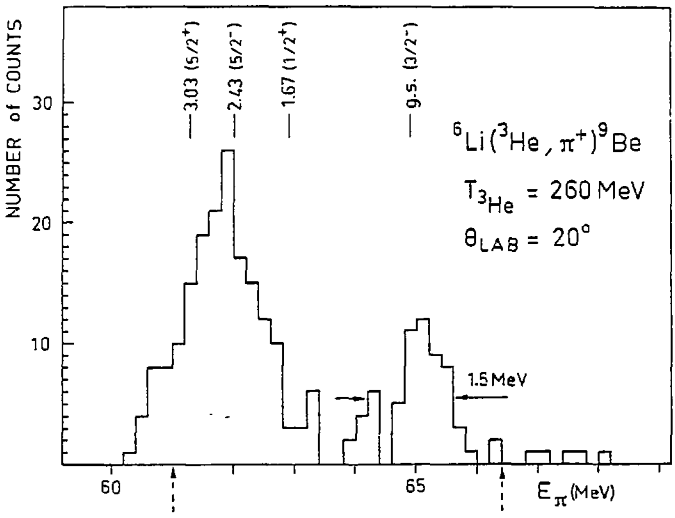
(Vertical arrows indicate efficiency limits in energy).

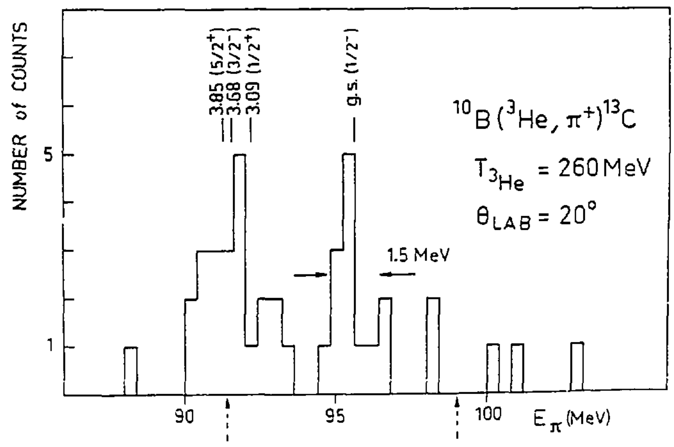
Figure 2 : Angular distributions for the $^{6}Li(^{3}He,\pi^{+})^{9}B_{g.s.}$ reaction. The reaction energies are shift of 1 MeV compared with incident energies by energy loss in half target.

(The curves correspond to calculations of GERMOND(10) .

Figure 3 : Energy dependence at $20°_{Lab.}$ of the cross section for $^{6}Li(^{3}He,\pi^{+})^{9}Be_{g.s.}$ and $^{10}B(^{3}He,\pi^{+})^{13}C_{g.s.}$ reactions.

(The curve corresponds to calculations of GERMOND(10).


NUMBER of COUNTS
10
20
30
60
65
E_π(MeV)
3.03 (5/2+)
2.43 (5/2−)
1.67 (1/2+)
g.s. (3/2−)
1.5 MeV
^{6}Li(^{3}He, π^+)^{9}Be
$T_{^3He}$ = 260 MeV
θ_{LAB} = 20°


NUMBER of COUNTS
1
5
90
95
100
E_π(MeV)
3.85 (5/2+)
3.68 (3/2−)
3.09 (1/2+)
g.s. (1/2−)
1.5 MeV
^{10}B(^{3}He, π^+)^{13}C
$T_{^3He}$ = 260 MeV
θ_{LAB} = 20°

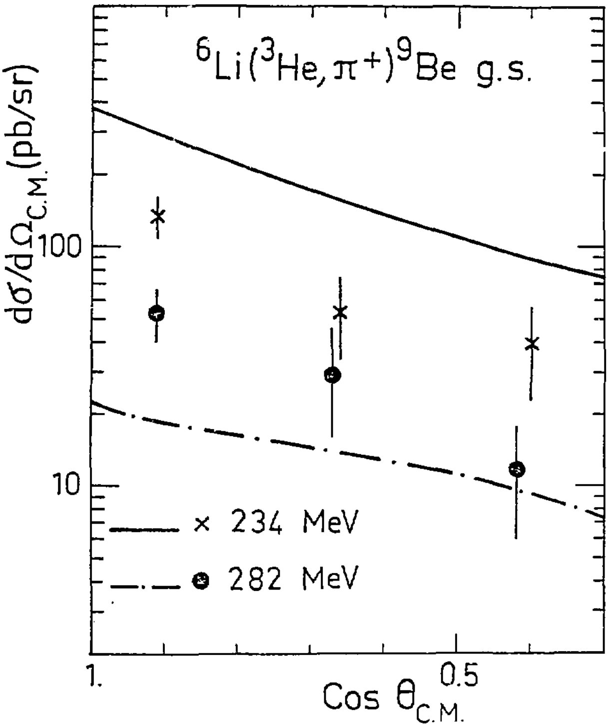
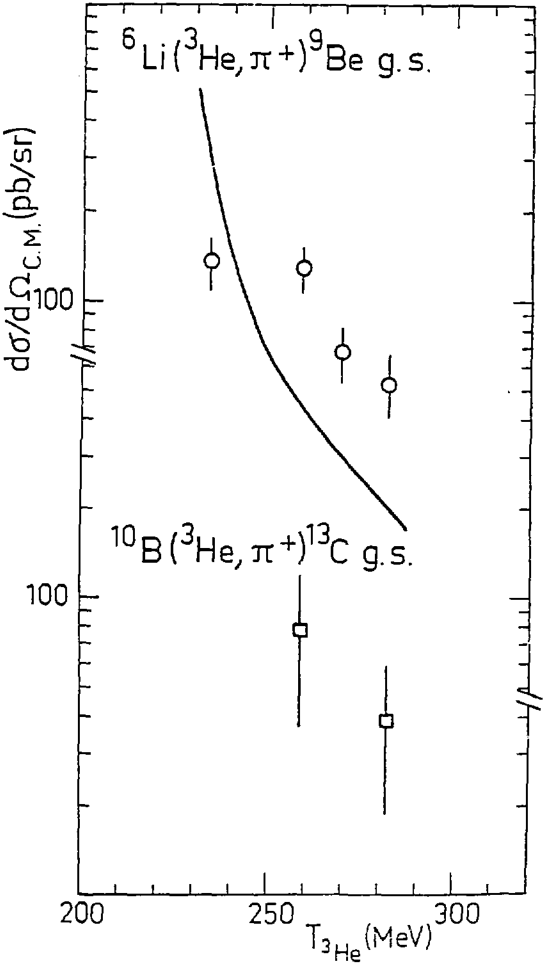


Fig. 2


$^{6}Li(^{3}He,\pi^{+})^{9}Be$ g.s.
$^{10}B(^{3}He,\pi^{+})^{13}C$ g.s.
$d\sigma/d\Omega_{C.M.}$(pb/sr)
100
100
200
250
300
$T_{^{3}He}$(MeV)