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ABSTRACT

The angular variation of the α-particle spectra from the reaction $^3He(^3He,\alpha)2p$ has been measured at 43.7 MeV and 53.0 MeV laboratory energy. The energy spectra show a prominent peak at the high energy end and the angular distributions of this peak exhibit a very pronounced diffraction pattern. Good fits to the energy spectra are obtained with the Watson-Migdal final-state formalism using the known p-p scattering parameters.

Recent Letters[1,2] have reported spectra of the $^3He(^3He,\alpha)2p$ reaction at 26 MeV[1] and at 11.96 MeV[2] laboratory energy, bearing qualitative evidence for the p-p interaction. The spectra at 26 MeV have not been analyzed theoretically, but at 6° in the laboratory system the 2p interaction seems to dominate the spectrum. A fit using the Watson-Migdal formalism[3] was produced for the 11.96 MeV spectra,[2] but the agreement is partially obscured by the contribution of the p-α interaction (Li^5), prominent at the angles investigated.

There is continued interest in the study of reactions leading to the $^1S_0$ state of two nucleons, particularly with regard to the determination of the scattering parameters of the n-n interaction.[4] The usefulness of the deuteron break-up reaction n + d → n + n + p for such purpose has been recently

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questioned, and the Watson theory seems to be misleading in this reaction.[5] The existing data on the mirror reaction $p + d \rightarrow p + p + n$ indicate that the p-n interaction obscures the effects of the p-p interaction.[6,7] On the other hand there are indications that the peaks observed in angular correlation measurements are sharper than can be predicted by the Watson-Migdal formalism.[8] This would indicate an effect in the right direction to explain the discrepancy between the value obtained for the n-n scattering length a_n from the $d(\pi^-,\gamma)2n$ [9] the $^3H(d,^3He)2n$ reactions,[4] and the values obtained from the n+d experiments.[10,11] Recent work on the reactions $^2H(^3He,t)2p$ and $p(^3He,d)2p$ has been reported,[12] showing the spectra of the third particle to be sharper than predicted by the known p-p scattering parameters in the context of the Watson-Migdal formalism. In each reaction qualitative reasons for such an observation can be found, like the charge exchange effect that may dominate the $^2H(^3He,t)2p$ reaction,[13] and the known diffuseness of the outgoing deuteron in the $p(^3He,d)2p$ reaction. It should be noted that the scattering lengths required to fit the spectra from the $p(^3He,d)2p$ [12] and $^3H(n,d)2n$ [14] reactions seem larger than the currently accepted values of these quantities. The same is true for the $^2H(He^3,t)2p$ reaction[12] mentioned above, indicating that spectra from the reaction $d(t,^3He)2n$ may also require a large value of a_n. No such data are presently available. Evidence of a similar correlation might be obtained from a study of the reaction $^2H(t,^3He)2n$, as it could also require a high value for a_n. The physical fact is that all such reactions lead asymptotically to three particles in the final state, and this is true for Breit-Wigner resonances between pairs of particles, as well as for virtual or antibound "states". Thus, neither the Breit-Wigner resonances nor the virtual states are true quantum mechanical states, and they are described by wave functions $\psi \notin L_2(0,\infty)$.[15] The Eisenbud[16]

interpretation of a rapidly increasing phase shift as a time delay, leads to the definition of a physical lifetime for both resonant and virtual states, and both manifest themselves by peaks in the energy spectra of the third particle. They can be elegantly interpreted in terms of poles in the scattering amplitude of two particles, and the question is how well can one extract the pole parameters from the spectrum shape (or "line" shape) of the third particle. Hence reactions leading to the 2p system and a third particle are useful to test a given theoretical formalism, if there is dominance of the p-p pole. Such comparison was made for the Watson-Migdal formalism using the ^{3}He(d,t)2p reaction over a wide range of energies.[2,17] Since there was good agreement between the calculated spectra and the experimental results, the mirror reaction ^{3}H(d,^{3}He)2n was used to determine a value and sign for the $^1S_0$ n-n scattering length a_n.[4]

We have studied the ^{3}He(^{3}He,α)2p reaction at 43.7 and 53.0 MeV laboratory energy (at target center), using the ^{3}He beam of the Berkeley 88-inch variable energy cyclotron. The detection was accomplished using solid state detector telescopes in conjunction with electronic particle identifier circuits.[18] Calibration spectra were obtained using the reaction ^{14}N(^{3}He,^{4}He)^{13}N*. The energy resolution was about 370 keV, in the relevant region of the spectra. The beam energy was determined by measuring its range in aluminum, using a Faraday cup and an electrometer.[19] The experimental techniques were basically the same as described elsewhere.[17] The large positive Q is quite helpful for the detection of the identified ^{4}He spectra over a sizable angular range, between 5° and 42° lab (10°-90° cm). A prominent peak near the high energy end of the alpha particle spectra was observed (fig. 1(a) and 1(c)). Its angular distribution follows a pronounced diffraction pattern with minima (fig. 1(b)) deeper than usual even for particle transfers leading to particle bound states or long lived

resonances. The angular distributions at both energies are shown in fig. 2(a) and 2(b) together with fits based on a diffraction picture of the reaction mechanism.[20] The P.W.B.A.[21] is inadequate in fitting the relative values of succesive maxima as well as in the positions of the minima. The rather large "interaction radii" r_i that fit the angular distributions, in excess of 4 F, lend support to the direct or peripheral picture of the reaction mechanism. Therefore it should be reasonable to expect that the transition amplitude can be factored into the product of a term containing a pole in momentum transfer and a term containing a pole in the nucleon-nucleon momentum. In the present case the rearrangement collision consists of an $\ell=0$ nucleon transfer. More complicated processes, like charge exchange, are excluded. The energy spectra are compared with the Watson-Migdal formalism predictions, using the formulae contained in ref. 4 and the known p-p scattering length, excluding the vacuum-polarization correction, $a_p \cong -7.7$ F.[22] Figure 3 contains several sample spectra showing a good agreement between the theory and the experimental results, over a considerable angular range. Our results indicate that the study of the reaction $^3H(t,\alpha)2n$ should prove relevant in obtaining additional information on the n-n interaction. In particular it should be interesting to ascertain whether the $^3H(t,\alpha)2n$ reaction yields a scattering length in agreement with the $^3H(d,^3He)2n$ reaction,[4] and thus also with the $\pi^- + d$ experiment.[9] If there is agreement then, hopefully, properly chosen reactions, with an outgoing third particle having a sharply defined boundary, may allow in the future a more precise and complete determination of the $^1S_0$ n-n scattering parameters.

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FIGURE CAPTIONS

Fig. 1. ^{4}He spectra from the reaction ^{3}He + ^{3}He → ^{4}He + 2p. A pulser group is seen at the far right.

a) At 17° Lab with 43.7 MeV bombarding energy. The arrow indicates the interval expanded in Fig. 3 b).

b) At 10° Lab (near the first minimum of the 2p enhancement), with 43.7 MeV bombarding energy.

c) At 16° Lab with 53.0 MeV bombarding energy.

Fig. 2. Angular distribution of the ^{3}He + ^{3}He → ^{4}He + 2p peaks integrated to a value where they drop to 1/e of the value at the maximum. The solid line corresponds to a fit with $J_0^2(q,r_i)$, the dashed line is the PWBA fit.

a) Data at 43.7 MeV. The $J_0^2(q,r_i)$ fit was calculated with r_i = 4.6 F The PWBA fit was obtained with r_i = 5.5 F.

b) Data at 53.0 MeV. The interaction radii are respectively r_i = 4.2 F and r_i = 5.0 F for the $J_0^2(q,r_i)$ and PWBA fits.

Fig. 3. The solid lines are fits to the ^{4}He energy spectra obtained with the Watson-Migdal formalism using a_p = -7.7 F, after folding the energy resolution and the effect of the finite angular resolution of the detector (approximately ± 0.3°). The solid dots are the experimental points.

a) Spectrum at θ_{Lab} = 5° and 43.7 MeV bombarding energy.

b) Spectrum at θ_{Lab} = 17° and 43.7 MeV bombarding energy.

c) Spectrum at θ_{Lab} = 5° and 53.0 MeV bombarding energy.

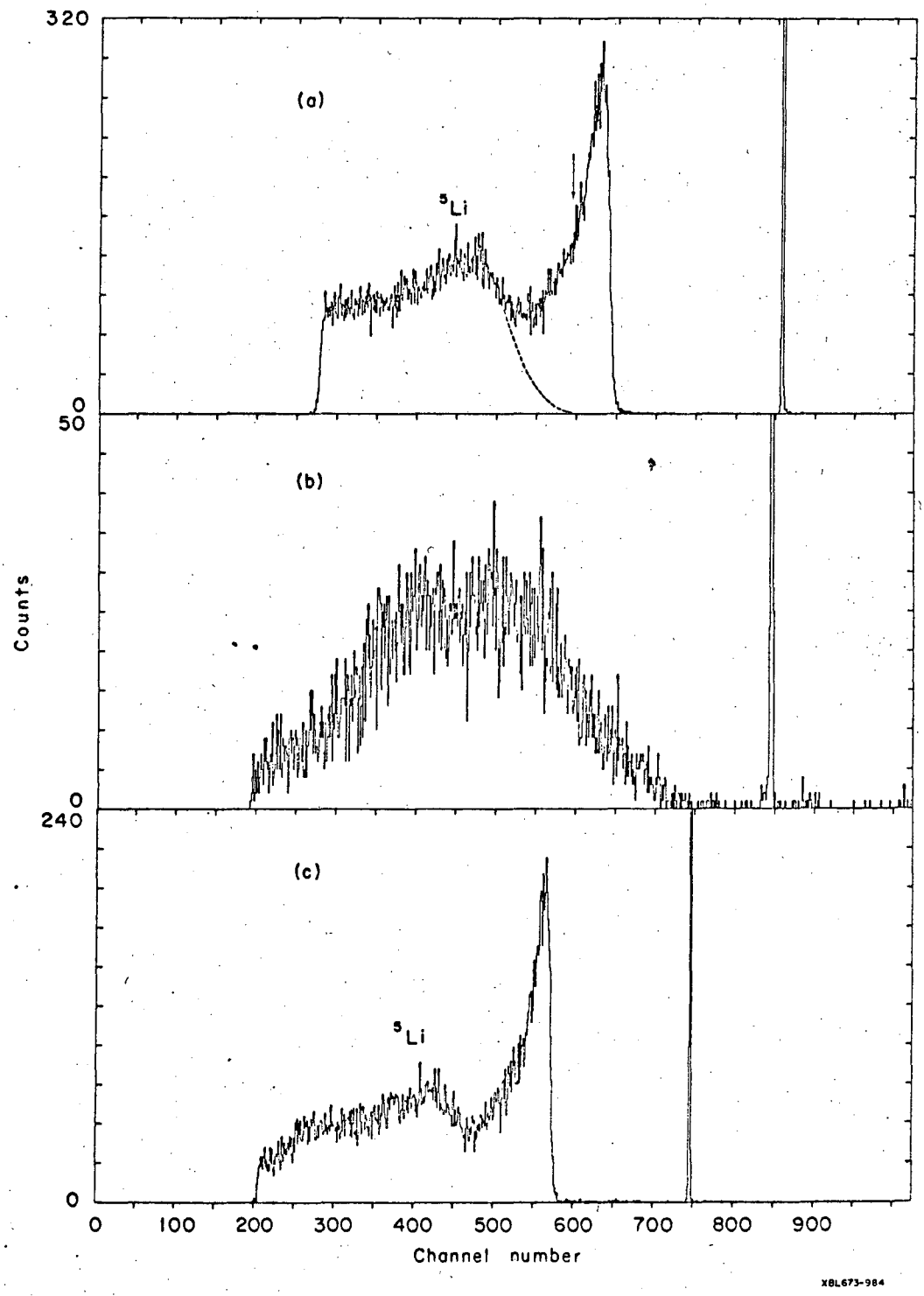
320
0
50
0
240
0
(a)
(b)
(c)
^{5}Li
^{5}Li
Counts
0
100
200
300
400
500
600
700
800
900
Channel number
XBL673-984

Fig. 1

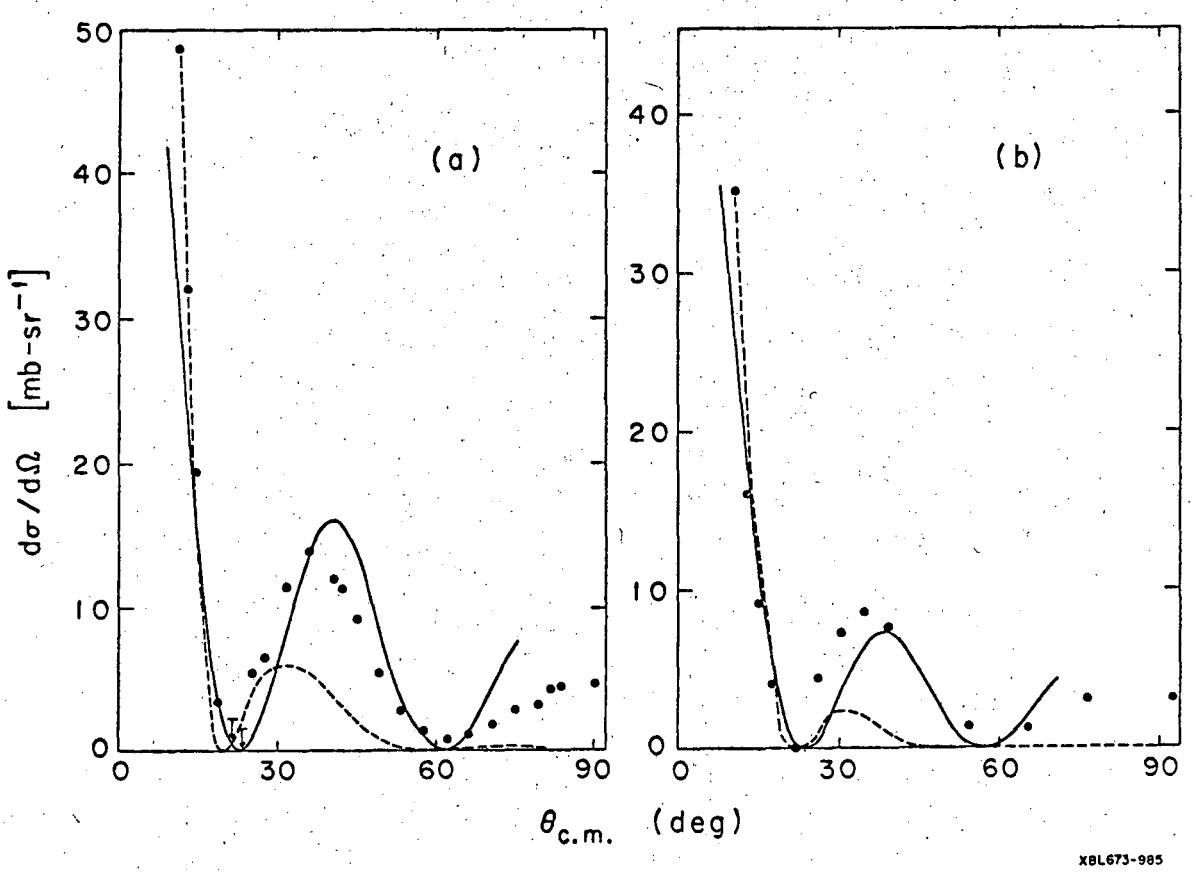

Fig. 2

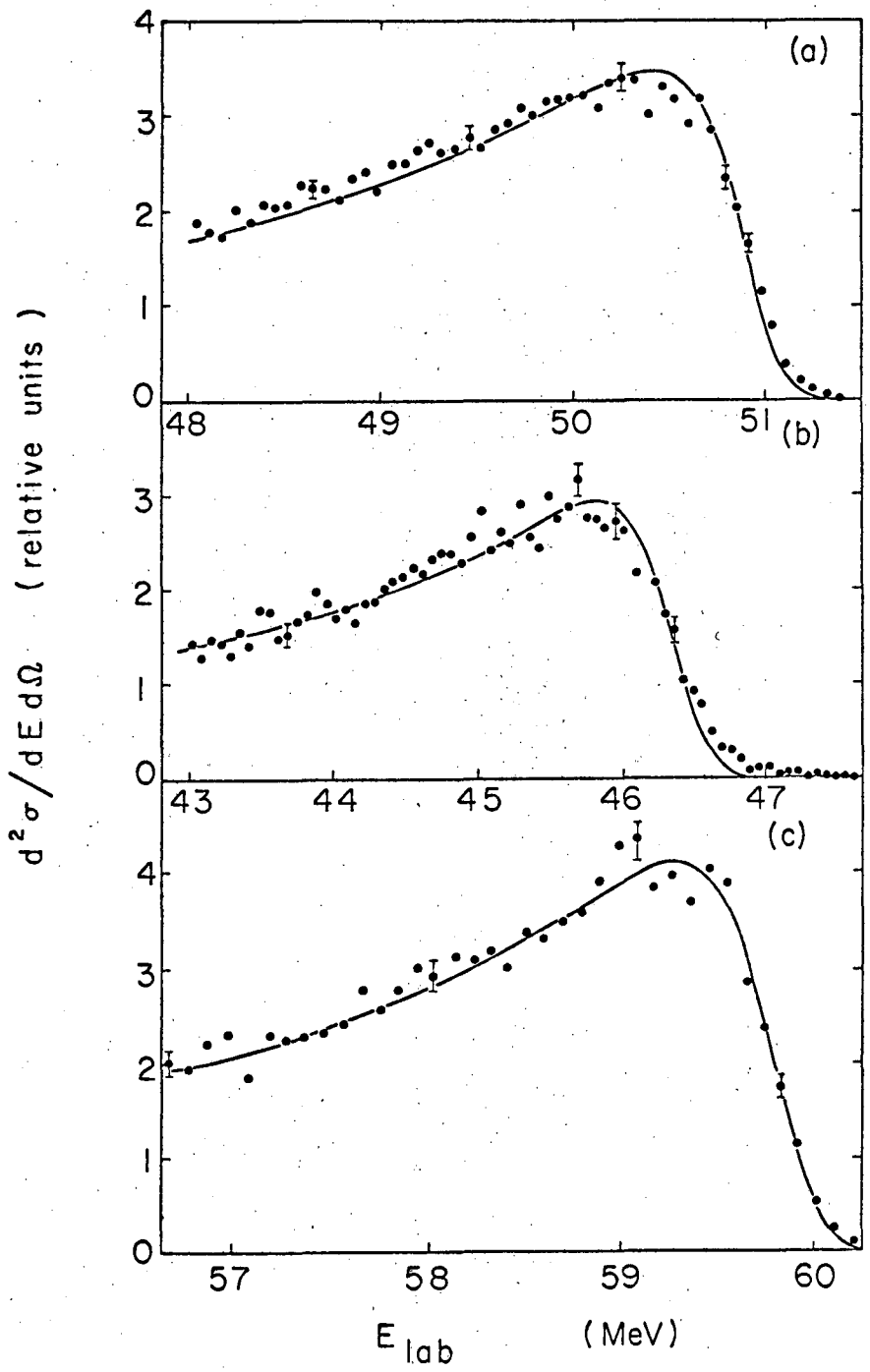
(a)
(b)
(c)
$d^2\sigma/dE\,d\Omega$ (relative units)
E_{lab} (MeV)
0
1
2
3
4
48
49
50
51
43
44
45
46
47
57
58
59
60

Fig. 3

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