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It is well known that a pion cannot be absorbed by a single free nucleon, owing to simple energy - momentum conservation. In the presence of bound nucleons, as in the case of nuclear matter, absorption on a single nucleon can be allowed, since the residual nucleus can provide for the necessary momentum-energy balance, but seems to be depressed as compared to the absorption on a nucleon pair. This leads to a quasi-deuteron model of the nucleus for explaining the pion absorption mechanism⁽¹⁾. However, the calculations based upon this nuclear model yield only a partial explanation of the experimental data. As a matter of facts, the amplitude $\pi NN \rightarrow NN$

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cannot give a complete account of experimental data, especially in reactions with many bodies in the final state. One is therefore led to take into account all the possible reaction mechanisms (absorption on a single nucleon or on more complex structures) together with strong interactions in the final state.

As an example of pure pion absorption we can mention the $(\pi^+, 2p)$ experiments of Favier et al.⁽²⁾, explained in terms of the theory of absorption on a deuteron. On the other hand, the experiments of Kaufman et al.⁽³⁾ looked at the absorption and double charge exchange of negative pions with two, three or four neutrons in the final state, while the experiments of Cernigoi et al.⁽⁴⁾ sought for pion interactions with charged particles in the final state (protons, deuterons, tritons).

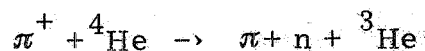
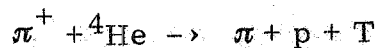
Among the nuclear structures which can be used in the study of pion interaction and absorption mechanisms, the α -cluster model appears to be rather attractive^(5, 6, 7, 8). Recent experimental results on pion absorption and scattering by even-even nuclei^(9, 10, 11) seem to be satisfactorily explained in terms of the α -model. According to the above considerations, the great interest for a detailed study of the pion - α particle interaction is fully justified especially as far as inelastic reactions (with and without charge-exchange) and absorption are concerned.

The experiments aimed to investigate the overall behaviour of $(\pi^\pm, {}^4\text{He})$ cross sections have been very few up to now, owing to the experimental difficulty in collecting complete information upon the many bodies present in the final state. First Fowler et al.⁽¹²⁾ studied elastic and inelastic interactions of pions with Helium nuclei in a diffusion chamber at three energies: 53(π^+), 68(π^-) and 105(π^-) MeV. Kozodaev et al.⁽¹³⁾ carried out an experiment with positive and negative pions at 273 and 330 MeV respectively on a diffusion chamber fil

led with Helium and observed all the processes involved: elastic and inelastic scattering and non-radiative absorption. Similarly, Budagov et al. (14) observed those processes in a diffusion chamber, by using 154 MeV negative pions.

According to these experiments, the prevailing mechanisms seem to be the interaction with a single nucleon and the quasi-elastic scattering from bound nucleons, possibly corrected for multiple scattering effects. In order to gain a deeper insight of this mechanism, it can therefore be useful to compare the results of the $(\pi^\pm, {}^4\text{He})$ interaction with the corresponding available experimental data on Hydrogen.

In this paper, we present the results of the π^+ inelastic interaction and absorption on ${}^4\text{He}$, at 110 and at 160 MeV and in the angular range 10 to 180 deg. In particular, we discuss the reactions



while the detailed analysis of the other processes will be the object of a next work. The elastic scattering component of our data has been presented in a preliminary form at the Los Angeles Conference (15). The final elastic cross sections are in good agreement with the results of the Dubna-Torino Collaboration (16, 17), obtained later and with a better statistics. In our experiment, we used the LNF-LEALE positive pion beam (18), whose energy had a large distribution around the mean value of 140 MeV. The experimental results have therefore been grouped in two energy intervals: 110 ± 12 MeV and 160 ± 18 MeV. The particle flux through the chamber amounted on the average to approximately 8 particles per photograph. The operating cycle was determined to a considerable extent by the background conditions and was about 10 sec. The e^+ and μ^+ contamination of the pion beam has been measured by means of differential and integral range techniques and turned

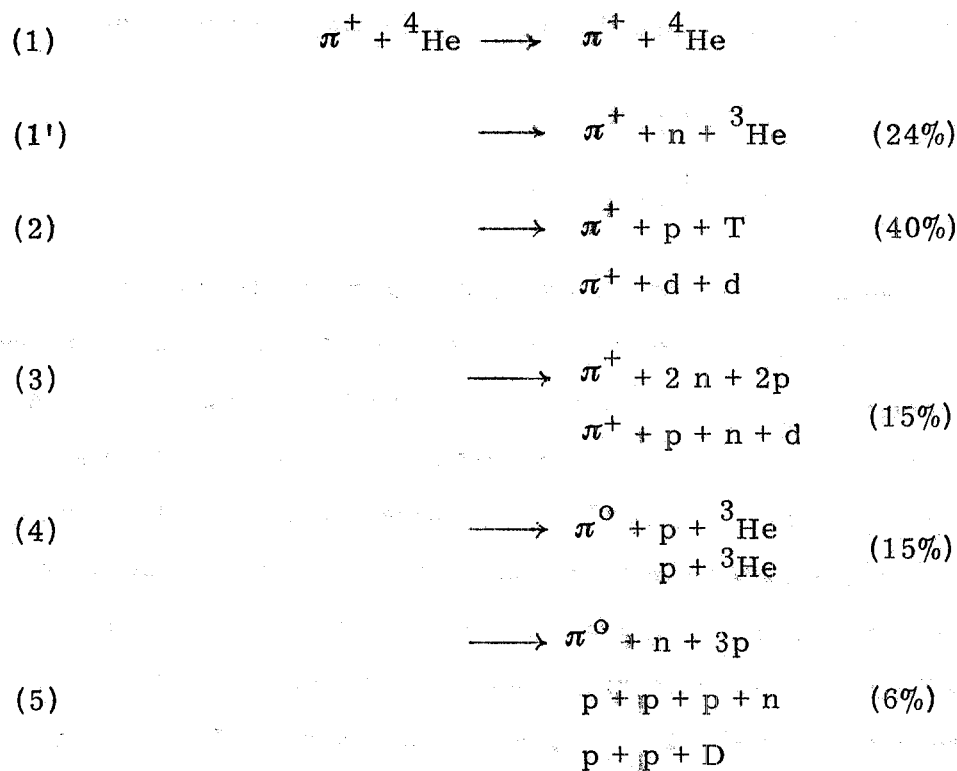
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out to be about 12%. The experimental apparatus consisted in a diffusion cloud chamber filled with Helium at 14 atm and placed in a magnetic field.

The apparatus and the experimental technique have been extensively described in ref. (19). Here we just recall that the magnetic field uniformity was $\sim 0.5\%$ throughout the sensitive volume of the chamber.

We collected about $6/10^4$ photographs for a total of 793 inelastic events, and a total track length of $7.2 \cdot 10^6$ cm.

The following reactions have been taken in consideration and analysed:



In parenthesis are reported the percentage of occurrence of each reaction normalized to the total number of inelastic events.

The reactions (1), (1') and (4) appear as two-prongs events. The remaining reactions show themselves as three-prongs

stars.

A double scanning of some of the films has been performed, in order to get the scanning efficiency. For two prongs events the efficiency turned out to be about 97%, and for three prongs events about unity.

In the course of scanning, reactions have been assigned to channels (1) to (5) according to the ionization of tracks and verifying, on the ground of kinematical considerations, the assignment of the reconstructed events. Each event has been digitized, on the scanning table, by measuring the coordinates of 8 points along each prong of the reaction. The reconstruction programs provide the geometrical and kinematical features of the reactions, both for two and for three bodies in the final state (i. e. energy of the incoming and outgoing pion, energy of the heavy particles as derived by the range-energy relations, etc.).

The accuracy on the measurement of the scattering angle turned out to be ≤ 1 deg. The accuracy on the measurement of the curvature radius depends upon the length of the radius itself and upon the length and spatial direction of the track. In our case, the resulting accuracy on the energy was 3% for tracks longer than 20 cm and 5% for tracks 10 to 20 cm long. The separation between the events of channels (1) and (1'), has been achieved by calculating, with the kinematics of the elastic reaction, the scattering angle and the energy of the α -recoil, on the basis of the measured values for the incoming pion energy and the scattered pion angle. The event has been assigned to the channel (1') whenever the angle and range of the heavy particle were different from the theoretical values by more than ± 5 deg and ± 5 mm respectively. Ionization criteria have been used for discriminating reaction (1') against reactions (4).

The identification of reactions (2) has been made particularly easy by the characteristic ionization of the outgoing prongs. Reac

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tions of the type



which are not kinematically separable from reactions (2) might be included in the number of these latter. However, on account of the small binding energy of the deuteron, we can assume the probability of occurrence of these reactions to be negligible. As far as the groups (3) (4) and (5) are concerned, single reactions have not been separated, owing to their complexity and uncertainty.

With such selection criteria, we obtained for the various channels the percentage of events listed above.

The total cross section for single reactions has been evaluated by counting the events and the total π meson track length within a rectangular fiducial region in the central part of the chamber, where the conditions for detecting particles were most favourable. The total cross section has been computed with the aid of the following formula⁽¹⁴⁾

$$\sigma = N\tau/L n_{\text{He}}(1-q)s$$

Where N is the number of occurrences of a given reaction in the prefixed region, L is the total track length of the incoming pions, n_{He} is the number of ${}^4\text{He}$ nuclei/cm³ in the sensitive volume of the chamber with an effective pressure of 15 atm at the average temperature of -55°C; q is the μ^+ and e^+ contamination of the beam; s is the scanning efficiency; τ is a coefficient taking into account the scanning loss for events in which charged particles are emitted at angles φ close to 90° and 270°. In our case $\tau = 1$ for all the reactions. The total cross-sections corresponding to each reaction or group of reactions and to the elastic process are reported in table I.

TAB. I - Total elastic and inelastic cross sections (mb).

N	Reactions	$E_{\pi} = 110 \text{ MeV}$	$E_{\pi} = 160 \text{ MeV}$
1'	$\pi^+ + {}^4\text{He} \rightarrow \pi^+ + {}^4\text{He}$	$\sigma_T = 52.0 \pm 5.7 \text{ mb}^*$	$\sigma_T = 71.5 \pm 9.1 \text{ mb}^*$
1'	$\pi^+ + {}^4\text{He} \rightarrow \pi^+ + n + {}^3\text{He}$	$\sigma_T = 38.8 \pm 3.0 \text{ mb}$	$\sigma_T = 52.7 \pm 5.0 \text{ mb}$
2	$\pi^+ + {}^4\text{He} \rightarrow \pi^+ + p + T$ $\pi^+ + d + d$	$\sigma_T = 84.6 \pm 7.3 \text{ mb}$	$\sigma_T = 102.3 \pm 7.6 \text{ mb}$
3	$\pi^+ + {}^4\text{He} \rightarrow \pi^+ + 2p + 2n$ $\pi^+ + p + n + d$	$\sigma_T = 39.0 \pm 4.9 \text{ mb}$	$\sigma_T = 32.8 \pm 4.3 \text{ mb}$
4	$\pi^+ + {}^4\text{He} \rightarrow \pi^0 + p + {}^3\text{He}$ $p + \text{He}$	$\sigma_T = 22.3 \pm 3.7 \text{ mb}$	$\sigma_T = 48.6 \pm 5.3 \text{ mb}$
5	$\pi^+ + {}^4\text{He} \rightarrow \pi^0 + 3p + n$ $3p + n$ $p + p + d$	$\sigma_T = 13.1 \pm 3.0 \text{ mb}$	$\sigma_T = 15.1 \pm 3.1 \text{ mb}$

(x) - Integrated from $20^\circ + 180^\circ$ in c. m. s.

We now analyse in detail reactions (1) and (1'). We will show that these reactions can be considered as resulting from a quasi-free scattering on individual bound nucleons, by assuming the residual nucleus not to participate directly to the interaction with the incoming pion. This point of view is supported by the experimental angular distributions of the nuclei. Moreover, the figg. 1 and 2 show the differential cross sections of reaction (2) at 110 and 160 MeV, vs. the lab. angle of the scattered pion, together with the cross sections of the π^+ scattering from free protons according to the data reported by Giacomelli et al. (20). From a comparison among the angular distributions plotted in figg. 1 and 2, a fundamental similarity turns out to exist between the behaviour of $(\pi^+ + {}^4\text{He} \rightarrow \pi^+ + p + T)$ reaction and that of scattering from free protons. For the inelastic scat-

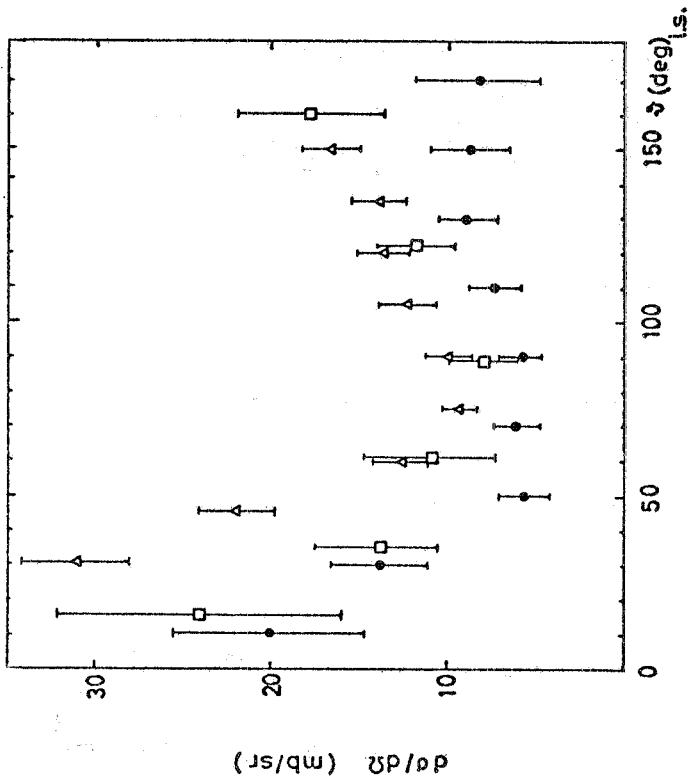


FIG. 2 - Differential cross-sections of reactions $\pi^+ + {}^4\text{He} \rightarrow \pi^+ + p + T$ at 160 + 18 MeV pion energy and $\pi^+ + p \rightarrow \pi^+ + p$ at 165 and 176 MeV, vs. the lab. angle of the scattered pion. The data concerning the π^+ scattering from free protons are from ref. (20).

- present work ($\pi^+ + {}^4\text{He} \rightarrow \pi^+ + p + T$)
- Δ ($\pi^+ + p$) - 176 MeV
- \square ($\pi^+ + p$) - 165 MeV

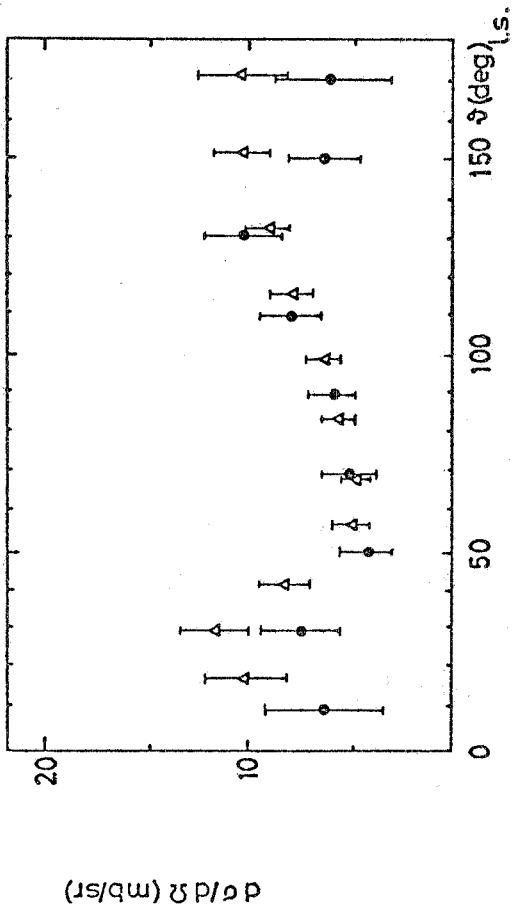


FIG. 1 - Differential cross-sections of reactions $\pi^+ + {}^4\text{He} \rightarrow \pi^+ + p + T$ at 110 + 15 MeV pion energy and $\pi^+ + p \rightarrow \pi^+ + p$ at 120 MeV, vs. the lab. angle of the scattered pion. The data concerning the π^+ scattering from free protons are from ref. (20).

- present work ($\pi^+ + {}^4\text{He} \rightarrow \pi^+ + p + T$)
- Δ ($\pi^+ + p$) - 120 MeV

tering from nuclei, Watson and Zemach⁽²¹⁾ tried to evaluate both the influence of coherent processes and the change in kinematical factors, on account of the fact that nucleons are scattered in a medium where the potential is non vanishing and depends upon the pion energy. According to such considerations, the Authors are able to work out a theoretical factor depending on the pion energy, by which the pion free nucleon cross section is to be multiplied for obtaining a fairly good reproduction of the pion scattering from ${}^4\text{He}$, mainly at large angles.

In the region of small angles ($\leq 40^\circ$) the suppression of $(\pi^+, {}^4\text{He})$ cross section can be possibly accounted for by observing that inelastic scattering from nuclei is forbidden for low momentum transfers to nucleons. Obviously the preceding considerations are qualitative. As a matter of facts, even in the assumption of negligible multiple scattering and absorption effects, the comparison should be carried out in the framework of some theory which properly took into account the pion-nucleus interaction as a whole, mainly with regard to the motion of nucleons inside the nucleus. By the way, all these arguments will be treated in detail in a next work.

Figg. 3 and 4 show the behaviour of the cross section for reaction (2) vs. the laboratory scattering angles between π incident and proton and π incident and tritium, for the two pion energies considered in this work. The analysis of the figures confirms our previous considerations upon the behaviour of the nuclei produced in reactions (1') and (2). More precisely, if such nuclei were involved as a whole in the interaction, some asymmetries should show up in the angular distributions of proton and tritium, corresponding to well defined kinematical correlations (for instance a divergence in opposite directions). On the contrary, the forward-backward asymmetry in the tritium distribution turns out to be fully consistent, within the experimental er-

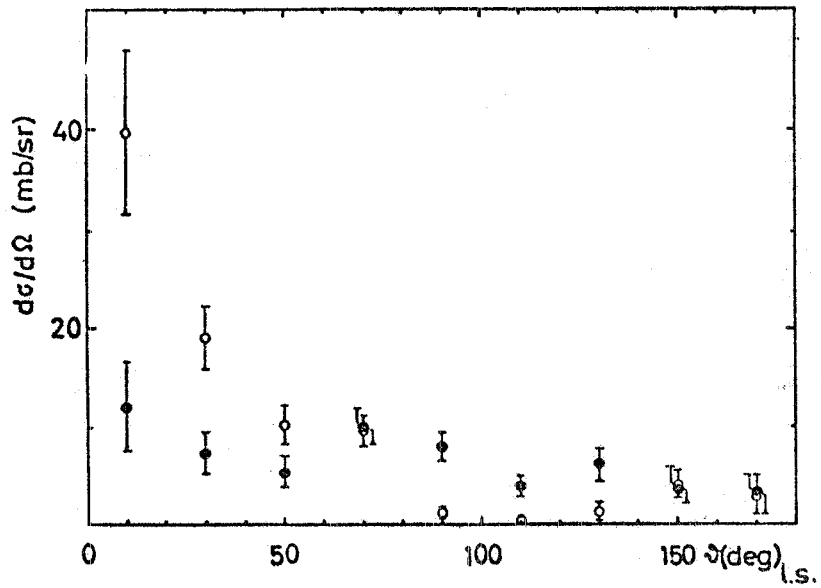


FIG. 3 - Differential cross-section of reaction $(\pi^+ + {}^4\text{He} \rightarrow \pi^+ + p + T$ at 110 ± 15 MeV pion energy vs the lab. scattering angles of π incident and proton and π incident and triton.

● proton; ○ triton.

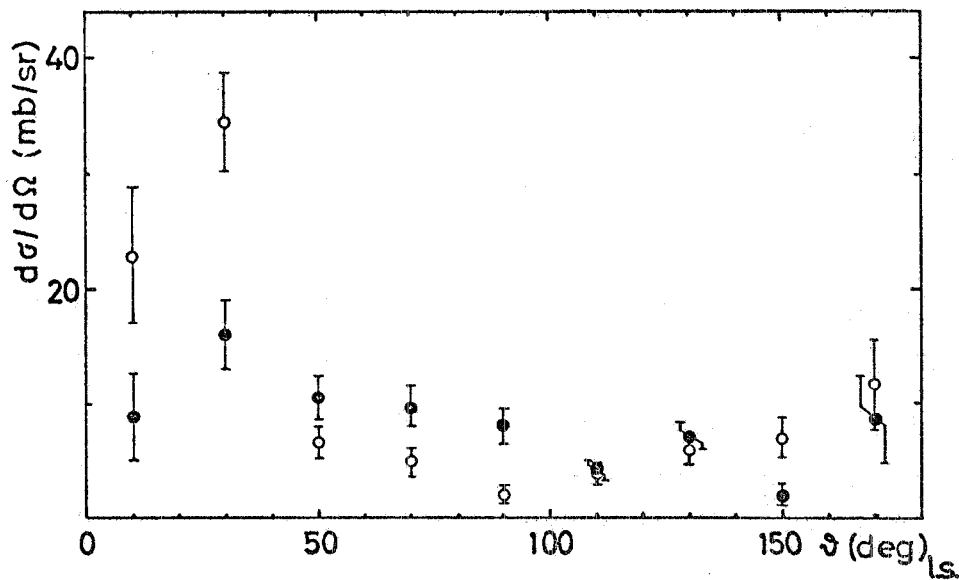


FIG. 4 - Differential cross-section of reaction $(\pi^+ + {}^4\text{He} \rightarrow \pi^+ + p + T$ at 160 ± 18 MeV pion energy vs the lab. scattering angles of π incident and proton and incident and triton.

● proton; ○ triton.

rors, with a quasi-spectator rôle played by this nucleus.

Figg. 5 and 6 show the angular correlation between proton and scattered pion both in reaction (2) and in scattering from free protons at the energies considered in this work. Here again the analogy is strictly in favour of a mechanism of direct interaction on a proton.

Figg. 7 and 8 show, for $E_{\pi} = 110$ and 160 MeV, the differential cross sections of processes (1') and (2) vs. the laboratory angle of the scattered pion, together with the differences, at the same energies, between the differential elastic cross sections of the $(\pi^+, {}^4\text{He})$ (16) and the $(\pi^+, {}^3\text{He})$ (17) scattering reactions. From these differences one can infer the behaviour of the cross section of π^+ on bound neutrons. Within the limits of the experimental errors, a good agreement is evident between the cross section of process (1') and the difference of the elastic cross sections. The differences between cross sections of processes (1') and (2), which can in some way be ascribed to the different π -N isotopic spin states involved, give a further evidence for a direct interaction mechanism.

As a conclusion, we feel quite safe to state that the features of reactions (1') and (2), together with their relatively high probability of occurrence, supports essentially a pion single nucleon interaction.

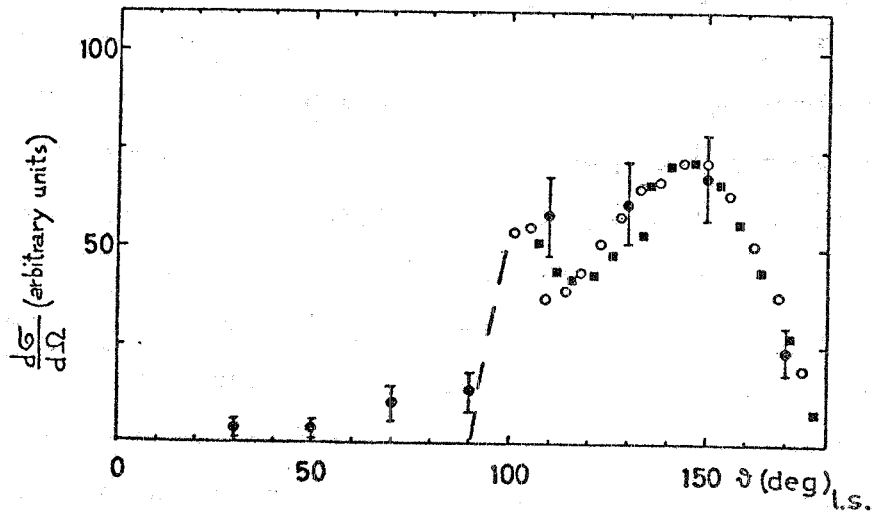


FIG. 5 - Differential cross section (in arbitrary units) of the reaction $\pi^+ + {}^4\text{He} \rightarrow \pi^+ + p + T$ at 110 ± 15 MeV pion energy vs. the lab. angle between scattered pion and proton. The dashed curve represents the same angular distribution for pion scattering on a free proton. Data are from ref. (26).

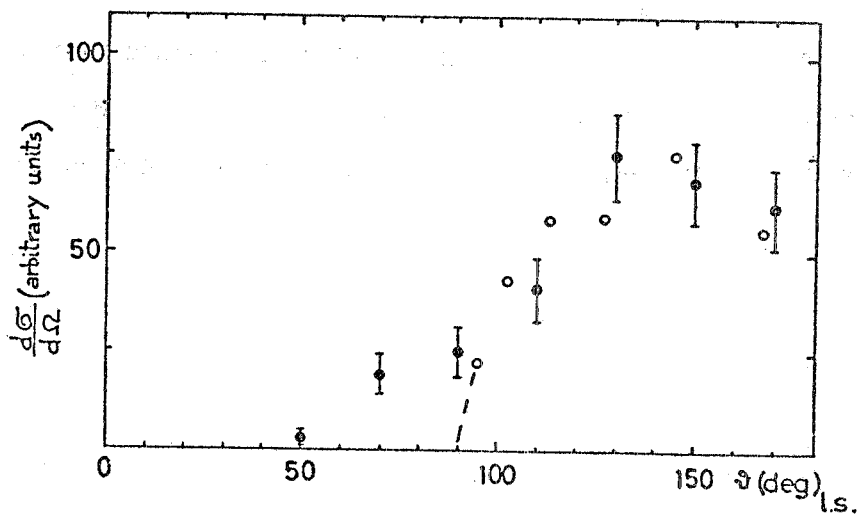


FIG. 6 - Differential cross section (in arbitrary units) of the reaction $\pi^+ + {}^4\text{He} \rightarrow \pi^+ + p + T$ at 160 ± 18 MeV pion energy vs. the lab. angle between scattered pion and proton. The dashed curve represents the same angular distribution for pion scattering on a free proton. Data are from ref. (26).

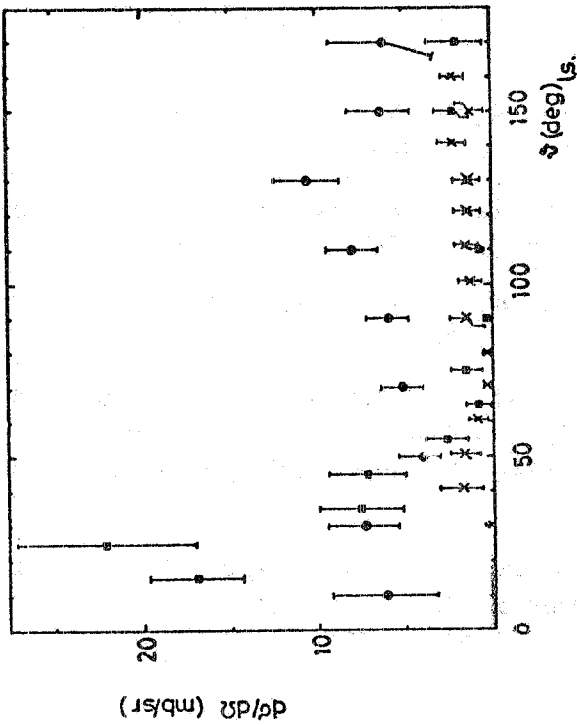


FIG. 7 - Differential cross-sections of the reactions $\pi^+ + {}^4\text{He} \rightarrow \pi^+ + p + T$, $\pi^+ + {}^4\text{He} \rightarrow \pi^+ + n + {}^3\text{He}$ and of the difference $(\pi^+ + {}^4\text{He})_{\text{elas.}} - (\pi^+ + {}^3\text{He})_{\text{elas.}}$ at 110 MeV pion energy vs. lab. angle of the scattered pion.

- $\pi^+ + {}^4\text{He} \rightarrow \pi^+ + p + T$ present work
- $\pi^+ + {}^4\text{He} \rightarrow \pi^+ + n + {}^3\text{He}$ present work
- × $(\pi^+ + {}^4\text{He})_{\text{el.}} - (\pi^+ + {}^3\text{He})_{\text{el.}}$ Experimental points from ref. (16, 17).

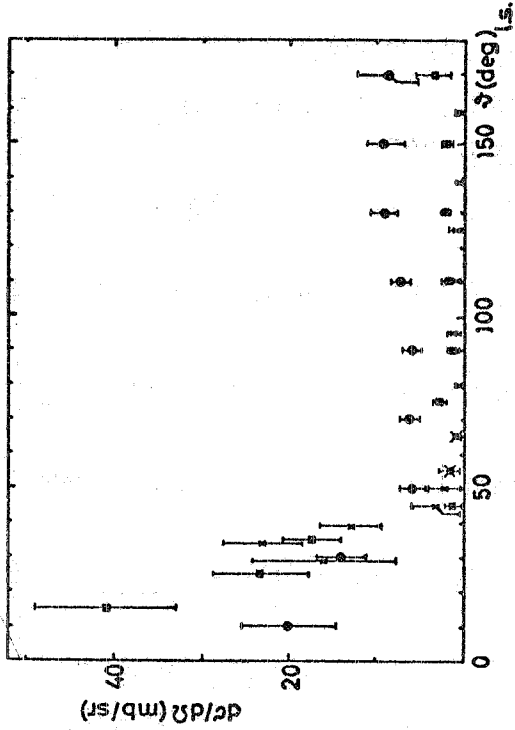


FIG. 8 - Differential cross-sections of the reactions $\pi^+ + {}^4\text{He} \rightarrow \pi^+ + p + T$, $\pi^+ + {}^4\text{He} \rightarrow \pi^+ + n + {}^3\text{He}$ and of the difference $(\pi^+ + {}^4\text{He})_{\text{elas.}} - (\pi^+ + {}^3\text{He})_{\text{elas.}}$ at 160 MeV pion energy vs. lab. angle of the scattered pion.

- $\pi^+ + {}^4\text{He} \rightarrow \pi^+ + p + T$ present work
- $\pi^+ + {}^4\text{He} \rightarrow \pi^+ + n + {}^3\text{He}$ present work
- × $(\pi^+ + {}^4\text{He})_{\text{el.}} - (\pi^+ + {}^3\text{He})_{\text{el.}}$ Experimental points from ref. (16, 17).

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