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LNF-75/59(P)
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F. Balestra, R. Barbini, L. Busso, R. Garfagnini, C. Guaraldo, R. Scrimaglio, and G. Piragino: (π^+, ^{4}He) INELASTIC INTERACTION AT 110 AND 160 MeV. II. - STUDY OF THE REACTIONS: $\pi^+ + {}^4He \rightarrow \pi^+ + 2p + 2n$, $\pi^+ + {}^4He \rightarrow \pi^0 + p + {}^3He$.

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F. Balestra[x], R. Barbini, L. Busso[x], R. Garfagnini[x], C. Guaraldo, R. Scrimaglio, G. Piragino[x]: (π^+, ^{4}He) INELASTIC INTERACTION AT 110 AND 160 MeV. II. STUDY OF THE REACTIONS:

$$\pi^+ + {}^4\text{He} \longrightarrow \pi^+ + 2p + 2n$$

$$\pi^+ + {}^4\text{He} \longrightarrow \pi^o + p + {}^3\text{He}$$

As well known many gaps must still be filled in the study of inelastic pion-nucleus scattering. A better understanding of this phenomenon will possibly enhance our knowledge of the nuclear matter transition density, in the same way as scattering of electrons provided informations on the charge transition density.

A number of interesting features can arise from an accurate analysis of (π^+, p) reactions is nuclei, with or without charge exchange. It should for instance be possible to correctly evaluate the pion-nucleon p wave contribution to the pion-nucleus optical potential, and to ascertain to which extent such nuclear reactions proceed through a

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direct interaction on nucleons or are affected by correlations and final state interactions.

From this point of view, the lightest nuclei (A = 2, 3, 4) are the best suited candidates for an accurate investigation by means of pion scattering. The ^{4}He nucleus, for instance, can be considered - - along with the deuteron and the ^{3}He nucleus - as an heavy "elementary particle", in attempting a connection between pion scattering and weak interactions (method of Adler-Weisberger) and in treating the "clustering" in more complex nuclei, as proposed recently by some Authors(1).

Furthermore, due to its relative small size, the ^{4}He nucleus is a good tool for checking the present knowledge of short range correlations and for emphasizing, at the proper energies, a possible breack down of the Glauber theory.

Experiments concerned with the investigation of the overall inelastic processes in ^{4}He have been performed, up to now, by Fowler et al.(2), Kozodaev et al.(3) and Budagov et al.(4).

In this letter we present the results of an experiment with positive pions on ^{4}He, involving the following processes:

(1) $$\pi^+ + {}^4He \rightarrow \pi^+ + 2p + 2n$$

(2) $$\pi^+ + {}^4He \rightarrow \pi^o + p + {}^3He$$

The experiment has been carried out by using a diffusion cloud chamber filled with Helium at 15 Atm and placed in a magnetic field. The positive pion beam was produced in the LNF-LEALE Laboratory(5) and showed a broad energy spectrum with a mean energy of 140 MeV about. The experimental data have been grouped in two energy bins: 110 ± 12 and 160 ± 18 MeV.

The experimental apparatus, together with its performance, has been previously described in a detailed work(6); similarly, the reader is referred to ref. (7, 8) for the results concerning elastic scattering and other inelastic processes. The criteria we used in the identification and analysis of the various inelastic processes detected by our apparatus are reported in ref. (8), together with total cross sections of all the processes, at the above pion energies. Here we just récall that both reaction (1) and (2) amount to 15% of the total inelastic events number[8].

Figg. 1 and 2 show the cross sections of reaction (1), vs. the angle of the scattered pion, (Lab. system). The basic isotropy of the cross section seems to suggest a pion interaction with the nucleus as a whole: Actually, processes where more than three particles are emitted in the final state can be interpreted in two ways.

From a first point of view, such processes can result from a simultaneous interaction of the pion with nucleon clusters. This hypotesis can be partially support ed by observing that a noticeable probability exsists of non-radiative capture by at least two nucleons. The lack of events such as (π^+, dd) does not diminish this argument, since the probability of emission of nucleon clusters in a bound state can be shown to be negligible[4]. Alternatively, these processes can proceed through the development of a nuclear cascade, as it can be easily inferred at least in those events where the two protons are emitted at right angles.

Reactions of type (1) can be classified, according to the terminology of Kozodaev et al.[3], as "multiple scattering processes": one pion is quasi-elastically scattered by a bound nucleon; further collisions of the pion with more nucleons or nucleon clusters give rise to a nuclear cascade. Upon the total of inelastic events without charge exchange, multiple scattering events have a relative probability of occurrence of about 25%. This probability can be profitably compared to those reported by Kozodaev et al.[3] (24%) for 273 MeV π^+, by Budagov et al.[4] (29%) for 153 MeV π^-, and by Kozodaev et al.[9] ($\simeq$ 22%) for

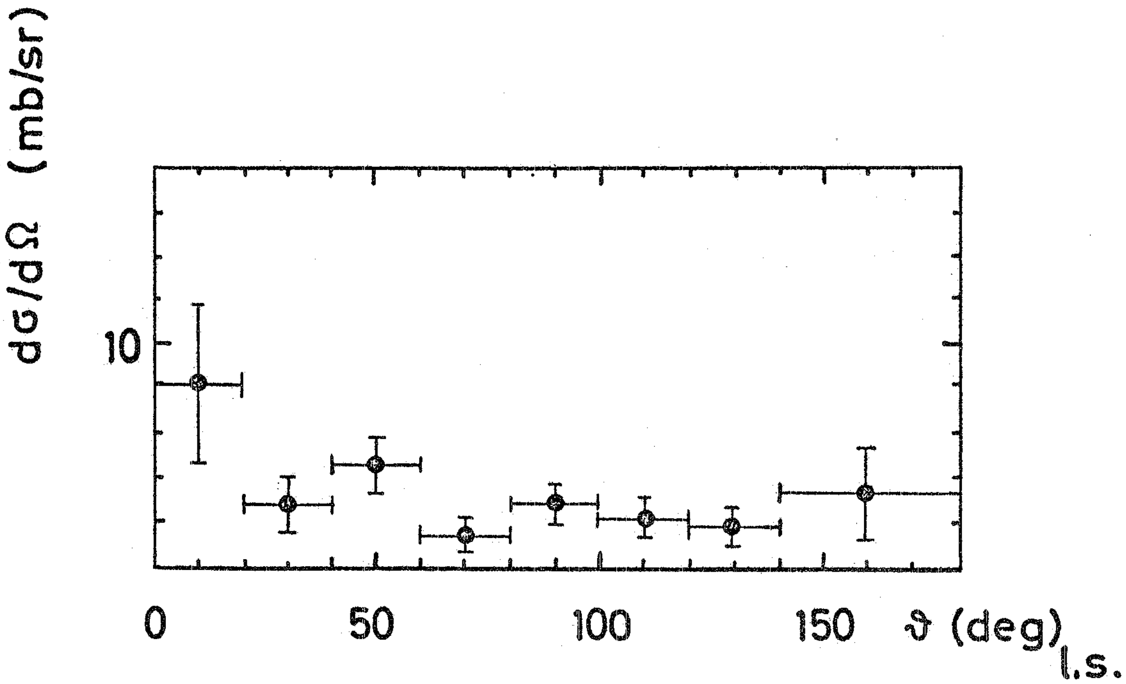

FIG. 1 - Differential cross-section of the reaction $\pi^+ + He^4 \longrightarrow$ $\longrightarrow$ $\pi^+ + 2p + 2n(1)$ at 110 $\pm$ 15 MeV pion energy vs. the Lab. angle of the scattered pion.

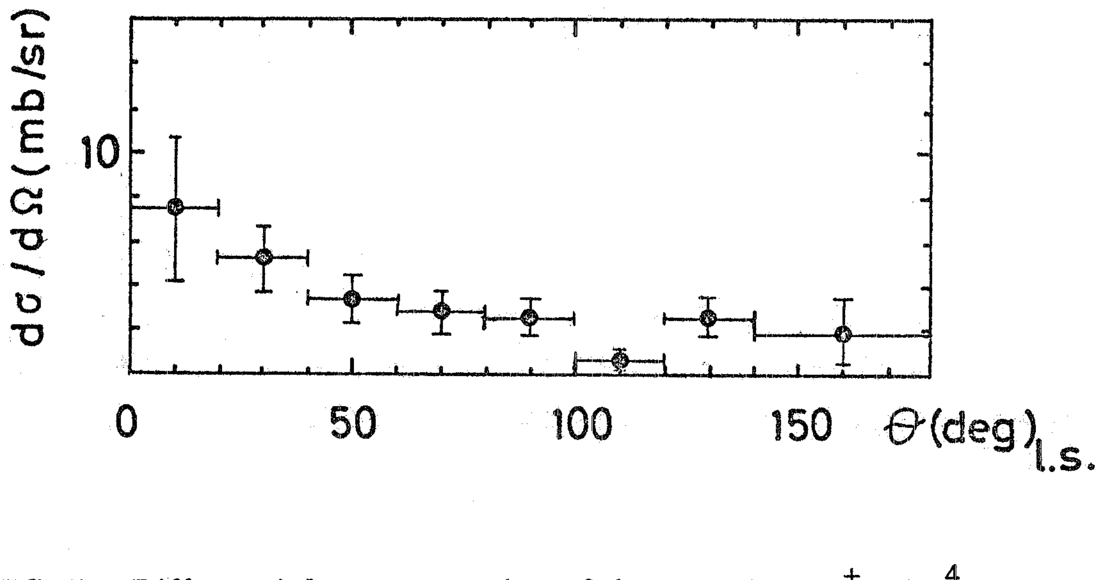

FIG. 2 - Differential cross-section of the reaction $\pi^+ + He^4 \longrightarrow$ $\longrightarrow$ $\pi^+ + 2p + 2n(1)$ at 110 $\pm$ 15 MeV pion energy vs. the Lab. angle of the scattered pion.

630 MeV protons on ^4He. From this comparison, it turns out that the role played by multiple scattering processes is rather important and, moreover, that they are independent of the energy and type of incoming particles.

As far as reaction (2) is concerned, it can be throught to involve a quasi-elastic scattering, with charge-exchange, of a pion upon a bound neutron. Obviously, process (2) is not the only possible charge-exchange process, since also the following can occur:

$$\pi^+ + {}^4He \rightarrow \pi^0 + n + 3p. \tag{3}$$

This reaction, however, cannot be distinguished, in our case, from absorption:

$$\pi^+ + {}^4He \rightarrow p + p + p + n, \tag{4}$$

and has been actually considered together with this latter.

In any case, process (3) can be looked at as a process of multiple scattering with charge exchange, on account of the fact that the absorption of a pion via (process (4)) this mechanism can be shown, with a cascade calculation, to have a negligible probability.

Reactions of the type

$$\pi^+ + {}^4He \rightarrow p + {}^3He$$

have not been separated in the present analysis. However, on the basis of simple energy-momentum considerations, they can be assumed to occur with a negligible probability.

We now limit ourselves to the analysis of reaction (2), by showing how the hypothesis of a prevailing interaction with a single nucleon can be justified.

In figg. 3 and 4 cross sections are reported, for T_{π^+} = 110 and

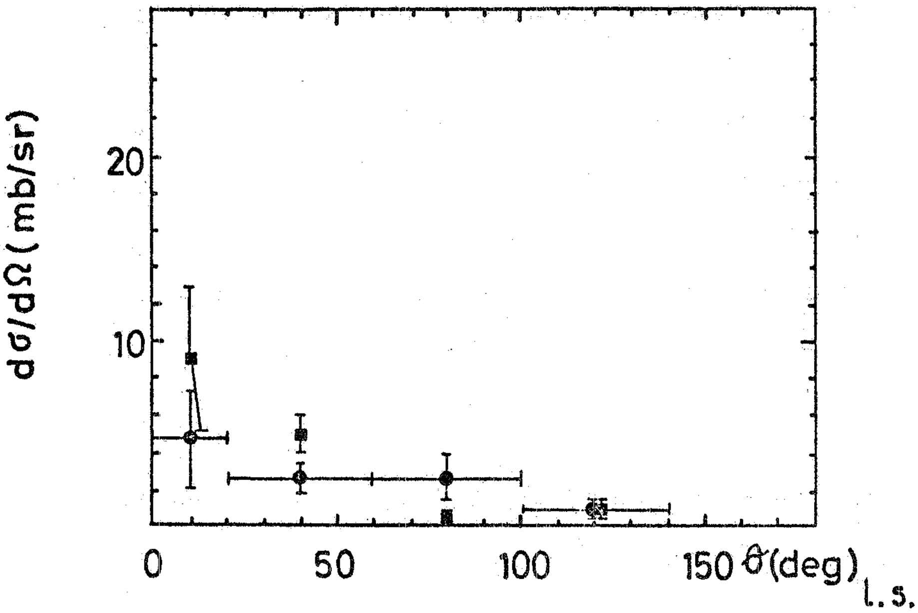

FIG. 3 - Differential cross-sections of the reaction $\pi^+ + He^4 \longrightarrow$ $\longrightarrow \pi^o + p + {}^3He$ (2) at 110 ± 15 M_eV pion energy vs. the Lab. angle between π-incident and proton and π-incident ${}^3He$.

• proton exp. points; ■ He^3 exp. points.

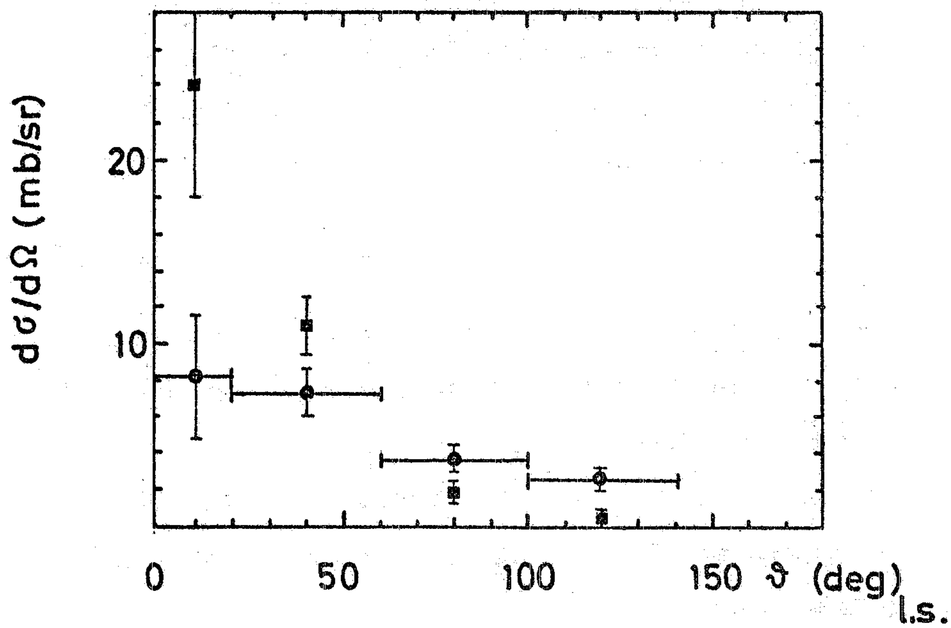

FIG. 4 - Differential cross-sections of the reaction $\pi^+ + He^4 \longrightarrow$ $\longrightarrow \pi^o + p + {}^3He$ (2) at 160 ± 18 MeV pion energy vs. the Lab. angle between π-incident and proton and π-incident He.

• proton exp. points; ■ He^3 exp. points.

160 MeV, vs. the two Lab. angles between incoming pion and outgoing proton and ^3He, respectively. The angular distribution of protons, forward peaked, is typical of an interaction with a single nucleon, while the distribution of ^3He's, not very far from isotropy, confirms this model.

The forward-backward ^3He asimmetry ratio can be explained in terms of pion multiple scattering effects and final state interactions. The single scattering hypothesis, however, can be confirmed further on by the comparison with the similar angular distribution of the reaction

(5) $$\pi^+ + {}^4He \rightarrow \pi^+ + p + T,$$

which has been shown to occur mainly via the single nucleon interaction channel[8].

It can be noticed that the angular distributions of protons in reaction (2) (Fig. 3 and Fig. 4) are much similar to the distribution of protons in reaction (5), as shown in ref. (8), while the tritons show a forward-backward asimmetry ratio smaller than that of ^3He, but also in this case the trends are very similar.

Our conclusion can also be confirmed by an estimate of the charge-exchange cross section based upon the values of scattering cross sections on free protons. This estimate can be performed by assuming the nuclear influence to be the same both in ordinary and in charge-exchange scattering and by correcting the pion energy for the nuclear repulsive potential[4,10]:

$$E_{\pi^+} = E_{o_{\pi^+}} - V_R(E_{o_{\pi^+}}).$$

Accordingly, the following ratio can be calculated:

$$R = \frac{(A-Z) \times \sigma_{E_\pi}(\pi^- + p \rightarrow \pi^o + p)}{Z \times \sigma_{E_\pi}(\pi^+ + p \rightarrow \pi^+ + p) + (A-Z) \times \sigma_{E_\pi}(\pi^- + p \rightarrow \pi^- + p)} \tag{6}$$

which gives[11]:

$R(E_\pi = 150 \text{ MeV}) = 0,15;$ $\quad R(E_\pi = 176 \text{ MeV}) \simeq 0.2.$

Equation (6) can be rewritten as:

$$\sigma_{exch}(E_{o_\pi^+}) = R(E_\pi)\, \sigma_{inel}(E_{o_\pi^+}).$$

With our experimental data(8):

$$\sigma_{inel}(E_{o_\pi} = 110 \text{MeV}) = 162.4 \text{ mb}$$

$$\sigma_{inel}(E_{o_\pi} = 160 \text{MeV}) = 187.8 \text{ mb}$$

we readily obtain

$$\sigma_{exch}(E_{o_\pi} = 110 \text{ MeV}) = 24.36 \text{ mb}$$

$$\sigma_{exch}(E_{o_\pi} = 160 \text{ MeV}) = 37.5 \text{ mb}.$$

The latter values are to be compared to those quoted in ref. (8): 22.3 and 40.17 mb respectively.

In any case, the pion-exchange cross section on ^4He is smal ler than the value one could expect on the basis of scattering on free nucleons. This quenching is probably connected to the exclusion principle[(x)] (and to parity conservation) and to the momentum distribution

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(x) - See pag. 10.

of nucleons in ^4He.

The general agreement between experimental data and calculations shows that an interaction model based upon the impulse approximation gives a raw, but satisfactory, interpretation of the experimental data.

(x) - The Pauli principle produces a destructive interference in charge-exchange scattering and a constructive interference in ordinary scattering. Moreover, the Pauli principle gives rise to a suppression in the forward amplitude of free scattering, since forward scattering implies a small momentum transfer to the nucleon.

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