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ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

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ON THE SECONDARY PROCESSES IN PION PRODUCTION ON NUCLEI

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A B S T R A C T

The calculation of pion production in p-C collisions at 660 MeV has been performed by the Monte-Carlo method. It is shown that pion scattering (with charge-exchange) changes essentially pion angular distributions and the ratio of positive and negative pion yields. The obtained angular dependence of this ratio is in agreement with experimental data.

I. INTRODUCTION

The study of pion production in high energy nucleon collisons with nuclei permits, in principle, to obtain information both on nucleon-nucleon and meson-nucleon interactions. In the framework of the present day theory of the nucleus this problem however cannot be solved exactly and, hence, one has to confine oneself to attempts of finding though an approximate solution. The interest to such solutions is due to the fact that they allow to obtain some informations on the properties of nucleon-nucleon processes without performing complicated experiments but basing on the results of comparatively simplier studies on nucleon interactions with nuclei (see, e.g.,[1-3]). In all similar investigations the circumstance that the interaction of fast particles with nuclear matter takes place, in general, in two-particle collisions has been used. This provides a possibility of employing a simple optical nuclear model the parameters of which are directly concerned with the cross sections of nucleon-nucleon and meson-nucleon reactions. At the same time the aim is to determine corrections accounting the scattering of nucleons by nuclear nucleons and the change of pion yield owing to the secondary processes: absorption and scattering inside the nucleus.

In the case of light nuclei where the secondary effects are not great these corrections turn out to be small for intensive reaction (such as $p+p \to \pi^+$ and $p+n \to \pi^0$) and, hence, it is easy enough to describe accurately experimental data with a model which takes into account the escape of nucleons and pions from the pion production process[1]. However, in the analysis of reactions of small intensity (e.g., $p+n \to \pi^-$) such a simplified model which does not take into consideration pion scattering cannot be employed since even in light nuclei the relative yield of negative pions should be increased considerably due to the scattering (with charge-exchange) of neutral pions* the loss of which, in its turn, is compensating owing to positive pion charge-exchange. Thus, the ratio of positive to negative pion yields Y^+/Y^- in proton collisions with the complex nucleus should be smaller than in the case with free nucleons, firstly, due to the increase of

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*If one overlooks this process, it is possible to come to a wrong conclusion on the large value of the cross section of the reaction $p+n \to \pi^-$ and to over-estimate the probability of pion production in the state with total isotopic spin T = 0, as it was made by Azhgirei et al[4].

negative pion yield, and secondly, due to a comparatively small decrease of positive pion yield. It follows from the above-said also that the value Y^+/Y^- should be a decreasing function of the bombarding nucleus weight. The described mechanism of changing the ratio Y^+/Y^- appears to be the basic one and explains the difference /5-8/ of the values Y^+/Y^- for deuterium and carbon*. The present investigation has been performed in order to check up quantitatively this assumption by comparing calculation results with existing experimental data.

2. CALCULATION PROCEDURE

The process of pion production was modelled by the Monte-Carlo method (see,e.g. /9/).The light C_6^{12} nucleus was chosen as a target bombarded with 660MeV protons. This nucleus proved to be acceptable because, on one hand, the probability of secondary interactions in such a nucleus is great enough and, on the other hand, the role of multiple collisions is not essential as yet, that considerably simplifies calculation.

Since the aim of calculation was to find out the role of the secondary processes and, in particular, the role of scattering but not to obtain the complete picture of pion production on nuclei, a simplified nuclear model was used without reducing the accuracy. The model did not take into account intra-nuclear motion (its role at the above-mentioned energies is not great /3/), whereas the density of nuclear matter was assumed to be constant in nuclear volume. The problem was solved in two stages: the process of pion production was imitated,scattering being and not being taken into consideration.Then the results were compared. Thus, the calculation was carried out by a relative method: e.g., we studied not pion angular distribution itself but its change owing to scattering in the framework of the same model, and as a result of this, the above-stated simplifications could not change considerably final results.

The calculation was performed according to the following diagram (in the cells of the diagram the kinds of the processes and the values to be determined are shown; q is the pion charge, $\vec{p}$ is its momentum, $\vec{r}$ is the point at which the event took place):

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*As is pointed out by B.Pontecorvo (private communication), the relative yield of negative pions can be increased due to pion production by recoil neutrons arising as a result of the primary proton scattering inside the nucleus. The evaluation performed by us has shown that the ratio Y^+/Y^- decreases approximately 10% due to this mechanism. This process should be essential at higher energies than ours.

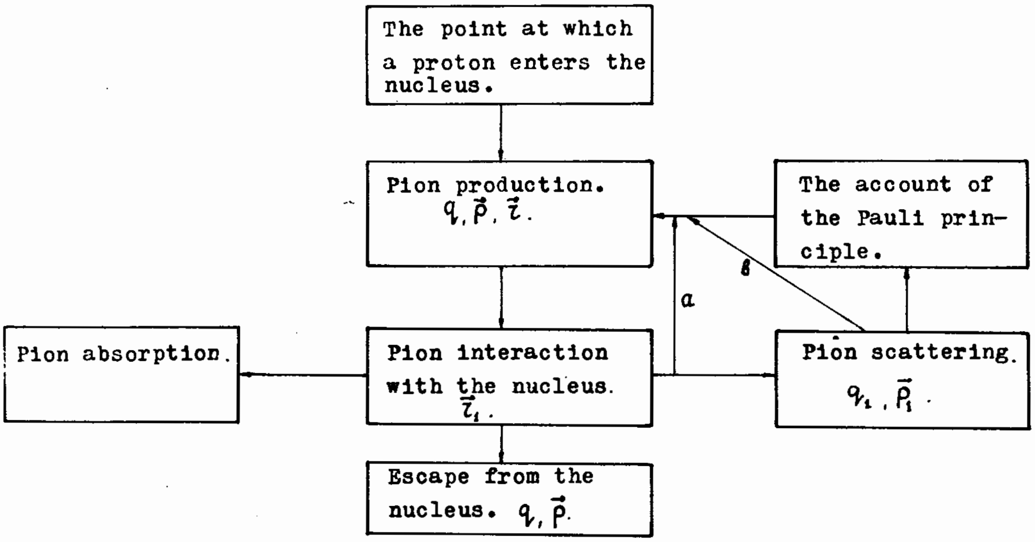

Fig.I. Calculation diagram.

The arrow "a" in the scheme corresponds to the first stage of calculation when pion scattering is not taken into consideration. Simultaneously the role of the Pauli principle was taken into consideration (calculation in the diagram by the arrow "b" and by the basic scheme). Such events when the recoil nucleon in scattering has an energy which is below the final Fermi energy were excluded from the last case. Calculations were performed by means of the URAL electronic computer. In order to determine the probabilities of various processes a lot of experimental information on the cross scetion value was used (see references of papers /3,9/). On the whole, 500 events of pion production inside the nucleus were imitated. 314 pions of them left the nucleus without undergoing the secondary interactions and only 15 pions interacted with nucleons twice.

3. RESULTS AND DISCUSSIONS

a)Change of total cross sections.

In 660 MeV proton collisions with a free proton and neutron pions of various signs are produced in the following ratios: Y^{+}/Y^{0} = 1.70 ± 0.12 according to /10/ and Y^{+}/Y^{-} = 9.0 ± 0.8 according to /5,6,8,10/. The performed modelling has shown that as a result of scattering with charge-exchange the value of the first ratio, as it was expected, changes negligibly: for carbon Y^+/Y^0 = I.6. At the same time the ratio of the yields of positive and negative pions decreases 1.5 ± 0.I times:

$$Y^+/Y^- = 6.1 \pm 0.6$$

This value is well consistent with $Y^+/Y^- = 6.2 \pm 0.5$ [5-8] obtained experimentally.

The effect of the Pauli principle at such high pion energies as in our case turned out to be negligible . Only 15% of scattering events could not be realized due to this "prohibition".

b) Change of angular distributions

Pion scattering on nuclear nucleons leads to the decrease of the asymmetry of pion angular distribution relative to 90° in the lab. system. Consequently, there must be an increase of the asymmetry of pion angular distribution in the centre-of-mass system (c.m.s.) of colliding nucleons, $f(\theta)$, which even without taking into account pion scattering should be essentially asymmetric due to proton scattering and pion absorption.[11] If one characterizes the angular distribution by the value $\eta = [f(180°) - f(0°)]/f(90°)$ then, as it is seen from Fig.2 where calculation results are given, the increase of asymmetry owing to pion scattering amounts to ≈ 30% for the case of neutral pion production and constitutes an appreciable fraction of the value η = 8o - 100% observed experimentally for carbon[11]. Hence, even in the case of intensive reactions, taking place in light nuclei, the scattering processes should not be neglected in the calculation of pion angular distributions* If the angular distributions of reactions of weak intensity ($p + n \to \to \pi^-$ in our case) are considered, then scattering processes are of great importance here. In particular, they cause a sharp decrease of the value $Y^+/Y^-(\theta)$ in the range of large angles (see Fig.3). As is seen from this figure, the values $Y^+/Y^-(\theta)$, calculated and measured at different angles, are in good agreement with each other. It is desirable that the sharp decrease of the value $Y^+/Y^-(\theta)$ at angles ranging from 120° up to 180° predicted by calculations should be checked up experimentally. The experimen-

*The comparison of Fig.2 of the present paper with Fig.5 of paper[I] shows that the changes of pion angular distribution caused by scattering and absorption are approximately of the same character. This allows to take into consideration the influence of meson scattering upon their angular distribution in the model employed in [1] by increasing slightly the coefficient of meson absorption in the nucleus.

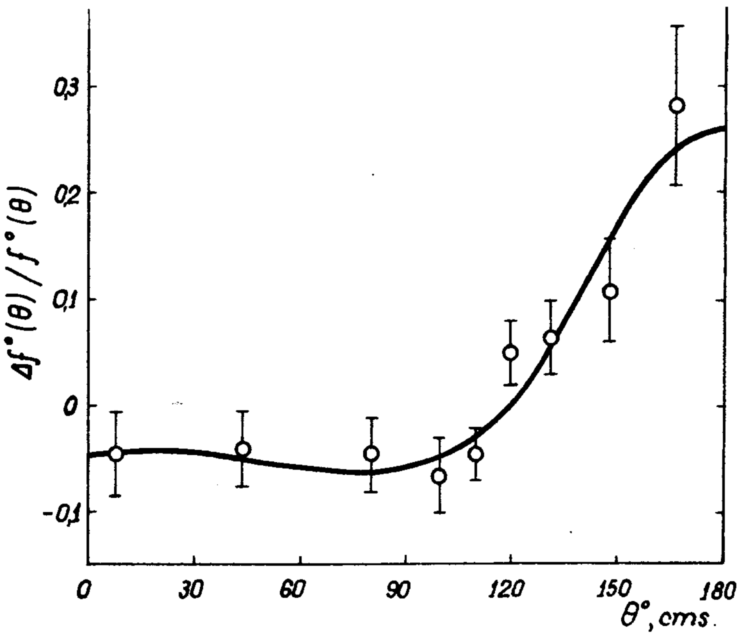

Fig. 2. Relative change of neutral pion angular distribution as a result of scattering. ϕ is obtained by the Monte-Carlo method. The approximation curve drawn by the least squares method is the polynom of the third power of cos θ

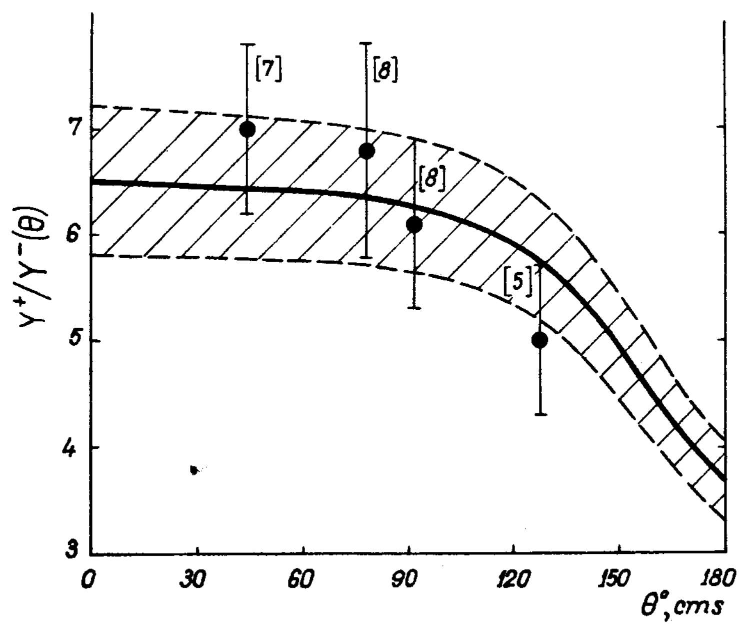

Fig. 3. Ratio of positive and negative pion yields $Y^{+}/Y^{-}(\theta)$ at various angles for carbon. The solid curve is a result of calculation by the Monte-Carlo method. The dashed curve indicates the corridor of errors. Φ denotes experimental data.

tal comparison of the asymmetries of negative and positive (or neutral) pion angular distributions is also of interest. The modelling has shown that owing to scattering the asymmetry of angular distribution of negative pions produced on carbon is 20-30% greater than in the case with positive pions.

4. CONCLUSION

The above comparison of calculation results by the Monte-Carlo method with experimental data has shown that in order to explain the observed picture of pion production on light nuclei a simple nuclear model which takes into account the scattering of pions produced on a nucleus can be used successfully. As for heavy nuclei, it should be noted that in this case scattering processes must be of greater importance. Due to this it should be observed that when nuclear weight is increased, the decrease of the ratio Y^+/Y^- and the appearance of a more distinct dependence of the value $Y^+/Y^-(\theta)$ on an angle and also the rapid increase of the asymmetry of pion angular distribution η take place. The last conclusion is in qualitative agreement with experimental data/11/. It should be mentioned that Metropolis et al./9/ have obtained a contrary result: the value η calculated by them for aluminium (at 460MeV) turned out to be greater than for lead. Probably, it is a result of poor statistical accuracy of calculation.

In conclusion one of us (Yu. D. P.) takes an opportunity to thank B.Pontecorvo for helpful discussions.

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