Double charge exchange of π^- mesons on nuclei with a change in strangeness

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Double charge exchange reactions of π^- mesons in nuclei with a change in strangeness ($\pi^- \to K^+$), as well as the $\pi^- \to \pi^+ K^\circ$ transitions, have been observed for the first time. A method is suggested for measuring the reaction cross sections without identification of the K^+ mesons. Experimental data indicate that the process, basically, has a two-step nature. Several nucleons of the nucleus ($n > 2$) can participate at once in the direction. The experiment was carried out in the MIFI five-hundred centimeter bubble chamber for $P_\pi = 3.9$ GeV/sec.

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Considerable attention has recently been focused on studying hadron-nuclear interactions involving the participation of several nuclear nucleons. Such processes also include the double charge exchange reaction of pions in nuclei.[1] There are systematic experimental data on this reaction up to an energy of 500 MeV, but the information at higher energies is very scanty.[2–4] One reason for this situation is the difficulty of identifying fast positively charged particles (separation of π^+ mesons and protons).

At sufficiently high energies the possibility arises for observing the even more exotic processes of double charge exchange of the primary particle with a change in strangeness. A study of this process yields the new information needed to establish the double charge exchange mechanism. This is most clearly evident in the case of negative pions. In a reaction involving a change in strangeness one of the neutral components, carrying information about the nuclear target, is a Λ hyperon, which is incomparably easier to study than the neutron of the "usual" double charge exchange.

It should be noted that the double charge exchange with a change in strangeness can serve as the source of the isobar-analog states of hypernuclei. Up to now a double change in the charge of the primary particle with a simultaneous change in strangeness had not been recorded.

We have observed for the first time $\pi^- \to K^+$ transitions in nuclei, and in some reactions kaons have been reliably identified from the $K^+ \to \mu^+ \to e$ decay.

The experiment was performed in the MIFI five-hundred centimeter Freon bubble chamber at $P_\pi = 3.9$ GeV/sec ($\bar{A} = 22.5$). Events with one relativistic positively charged particle or an obvious K^+ meson and one or two V° branchings were selected and measured. Nuclear accompaniment protons in the 0.2–0.7 GeV/sec momentum interval and γ quanta from electron-positron conversion pairs were also recorded. The average efficiency of the γ quanta recording is 56%. The selected events corresponded to the following processes:

TABLE I.

Quantity	Cross section, mb	Yield (σ, σ_{inelast})
$\sigma_1 + \sigma_2$	0.75 ±0.14	(2.0 ±0.4)·10^{-3}
$\sigma_2 + \sigma_3 + 2\sigma_4$	1.40 ±0.26	(3.7 ±0.7)·10^{-3}
$\sigma_1 + \sigma_2 + \sigma_3 + \sigma_4$	1.5 ±0.3	(4.0 ±0.8)·10^{-3}
$(\sigma_1 + \sigma_2 + \sigma_3 + \sigma_4)$ без π°	0.9 ± 0.2	(2.4 ±0.5)·10^{-3}
σ_1	0.41 ±0.17	(1.1 ±0.4)·10^{-3}
σ_2	0.34 ±0.12	(0.9 ±0.3)·10^{-3}
σ_3	0.44 ±0.41	(1.2 ±1.1)·10^{-3}
σ_4	0.31 ±0.15	(0.8 ±0.4)·10^{-3}

$$\pi^- + A \to K^+ + \Lambda(\Sigma^\circ) + mp + n\pi^\circ + A', \quad (1)$$

$$\pi^- + A \to \pi^+ + \Lambda(\Sigma^\circ) + K^\circ + mp + n\pi^\circ + A', \quad (2)$$

$$\pi^- + A \to K^+(\Sigma^+) + \bar{K}^\circ + mp + n\pi^\circ + A', \quad (3)$$

$$\pi^- + A \to \pi^+ + K^\circ + \bar{K}^\circ + mp + n\pi^\circ + A', \quad (4)$$

where $m, n = 0, 1, 2,...$ (relativistic protons are included in the "π^+" category). The Λ hyperons and K° mesons were identified by the standard method.[5] A total of 130 thousand photographs were analyzed; 162 events belonged to the reactions (1)–(4).

In view of the specific characteristics of the chamber experiment we reliably identified only the comparatively soft charged kaons, whose paths fit within the effective chamber volume. Thus, only part of the reactions (1), (3) have been experimentally identified. A possibility exists, however, for determining the cross sections of the $\pi^- \to K^+$ type processes even without identification of the K^+ meson by using strangeness conservation in nuclear interactions. To do this it is necessary to record not only the fast positive particle, but also the decays of the neutral strange particles. The total cross section of reactions (1) and (2) $\sigma_1 + \sigma_2$ is determined from the number of recorded Λ hyperons. The cross section σ_3 can be found from the number of recorded $K^\circ\Lambda^\circ$ pairs. The yield of K° mesons determines the value of $\sigma_2 + \sigma_3 + 2\sigma_4$. The cross section σ_4 is determined by the number of $K_1^\circ K_1^\circ$ pairs. The production cross sections of strange particles in the nuclei of the Freon mixture, previously measured by us,[5,6] were used for the normalization. The numerical values of all the quantities are given in Table I. Both the total cross section of the reactions (1)–(4) as well as the cross section of these reactions without the π° mesons are given. The last column of the table gives the ratio of the cross sections to the total cross section of the inelastic interaction of π^- mesons having a momentum of 3.9 GeV/sec with the average nucleus of the Freon mixture ($\sigma_{\text{inelast}} = 374$ mb). The cross section of processes with a π^+ meson in

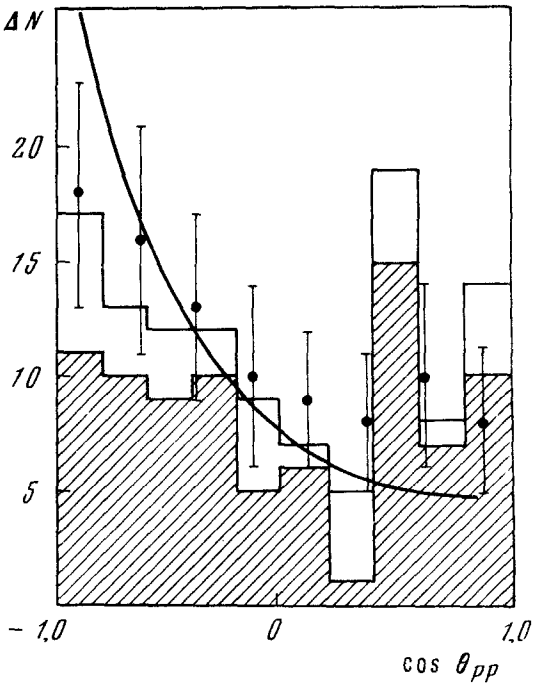

FIG. 1. Distributions with respect to the cosine of the angle between protons: histogram—all events, shaded portion—events with negative deficient mass, curve—absorption of stopped pions by carbon nuclei, points—$\pi^- \to 2\pi^+ \pi^-$ reaction.[4]

the final state amounts to 0.43–0.15 of the total cross section of (1)–(4). Estimates show that the correction to the cross sections, due to a possible admixture of slow π^+ mesons erroneously taken as protons, does not exceed 5%.

Up to now the mechanism of the double charge exchange reaction had not been definitely established. For the $\pi^- \to \pi^+ + (\pi^+\pi^-)$ reaction we had previously concluded that the reaction is two-step in nature when an additional soft π^- meson is formed in an elementary process in the first stage, and this is then absorbed in the second stage.[4] One of the arguments in favor of this conclusion was the characteristic divergence angle distribution of the two accompanying protons, very similar to the distribution in the "pure" capture of the stopped π^- mesons by nuclei. In the case being considered an analogous situation occurs (Fig. 1). The accompanying protons diverge basically at obtuse angles to each other. However, in contrast to the result of Ref. 4, "jets" of accompanying protons are clearly visible in the figure with a small opening angle for the divergence cone. If the events are sorted in terms of the amount of deficient mass relative to the recorded reactions products (excluding protons) for the assumption that the reaction proceeds in an at-rest (one) nucleon, then the "jets" are found to belong primarily to events with negative squares of the deficient mass. It must be added that for this same sorting we recorded reactions (1) and (2) with "cumulative" Λ hyperons, which can serve as an additional argument in favor of the collective nature of the interactions (1)–(4).[7] The contribution of the reactions with cumulative Λ hyperons amounts to $\sim$16% of the total cross sections of the reactions (1), (2).

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[1]Yu. A. Batusov, S. A. Bunyatov, V. M. Sidorov, and V. A. Yarba, Zh. Eksp. Teor. Fiz. **46**, 817 (1964) [Sov. Phys. JETP **19**, 557 (1964)].
[2]F. Gaille *et al.*, Nuovo Cimento A **40**, 31 (1977).
[3]N. M. Agabyan *et al.*, OIYaI Reports, R1-11158, Dubna, 1977.
[4]A. D. Vasil'kova *et al.*, Yad. Fiz. **21**, 1022 (1975) [Sov. J. Nucl. Phys. **21**, 525 (1975)].
[5]M. G. Gornov, *et al.*, Yad. Fiz. **27**, 1578 (1978) [Sov. J. Nucl. Phys. **27**, 831 (1978)].
[6]V. S. Demidov *et al.*, Yad. Fiz. **9**, 292 (1969) [Sov. J. Nucl. Fiz. **9**, 172 (1969)].
[7]M. G. Gornov, S.V. Lapushkin, A.K. Ponosov and F.M. Sergeev, Pis'ma Zh. Eksp. Teor. Fiz. **28**, 660 (1978) [JETP Lett. **28**, 610 (1978)].